FEB 23 1922

Vol. IV, No. 5 PSYCHOLOGICAL REVIEW PUBLICATIONS OCTOBER, 1921

Journal of Experimental Psychology

EDITED BY

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CONTENTS

The Relative Advantages of Distributed and Concentrated Study in Memorizing:
EDWARD S. ROBINSON 327

The Course of Events in Equilibrium Photopic Adaptation:
LEONARD THOMPSON TROLAND, 344

The [illegible] Reactions:
F. L. WELLS, C. L. KELLEY and
GARDNER MURPHY, 391

PUBLISHED BI-MONTHLY BY
PSYCHOLOGICAL REVIEW COMPANY
[illegible] ST., LANCASTER, PA., AND
PRINCETON, N. J.

Entered [illegible], 1917, at the post-office at Lancaster, Pa.

The combined results are given in Table VIII. Series II., composed of states, was regarded by the subjects as more difficult, but the general average of the association times is shorter than that of Series I., requiring false capitals for European countries. Usually the difference might be attributed to practice, and for some of the subjects that appears to be the case. *W* and *R. H.* learned Series I. first, and had a shorter association time than Series II. *M*, *B*, and *C*, learned Series II. first, and here practice effects appeared only with *B*. That is, practice effects are evident in three, and not apparent in two cases. With two subjects, *B* and *C*, the time of reaction in one of the check series is longer. They attribute it to the confusion arising from the names of certain county seats ending in 'ville.' In all other instances a shorter time was registered.

The manner of learning in both the test and check series followed the same lines. (1) Mnemonic devices where employed followed the same lines, *e.g.*, Kentucky-Mad-i-son. "Kentucky makes whiskey, whiskey makes madison." (2) Ingenious intermediaries were resorted to. (3) 'Straight-memory' as termed by the subject.

(*b*) *The Association of False Sums of Numbers.*—In general the procedure with this method followed that observed with the false capitals. Each series had only ten pairs, as given here.

Series V	Series VI	Check Series V
2 + 2 = 13	10 + 13 = 27	*L* + *P* = 8
1 + 3 = 2	9 + 14 = 20	*R* + *O* = 7
3 + 7 = 12	7 + 15 = 43	*G* + *M* = 12
4 + 5 = 7	11 + 12 = 19	*N* + *K* = 11
6 + 2 = 9	13 + 16 = 30	*Q* + *L* = 17
5 + 3 = 6	8 + 17 = 22	*B* + *E* = 13
8 + 3 = 23	12 + 14 = 28	*O* + *V* = 14
4 + 2 = 5	14 + 8 = 18	*K* + *R* = 19
2 + 7 = 15	6 + 9 = 16	*T* + *J* = 16
8 + 4 = 10	15 + 6 = 17	*D* + *C* = 21

Ten minutes were devoted to learning. Immediate recall was done by both writing and pronouncing the false or arbi-

trary associate as the experimenter pronounced the numbers or the letters of the series in an irregular order. After an interval of 48 hours a review of five minutes, with some subjects, eight minutes, was given. In the latter case, the same time was extended to the letter series, even though it was not needed. Twenty pairs of numbers and their true sums were used to ascertain the normal association time. This time based here upon 100 responses, is 1.535″ for true sums, and true capitals, based upon 140 responses, is 1.593″.

Results

Of the two series of numbers, V. and VI., the latter was considered the more difficult. This was due to the fact that Series V. contained all the simpler and smaller number combinations, and to avoid similarities in the two series, larger numbers had to be used. Although V. was given first, the effect of practice on VI. was obscured by its difficulty. Associating letters and their sums was considered less difficult than numbers and false sums by five of the subjects. The reason assigned was the difficulty in finding familiar and extra associations to serve as connecting bonds between numbers and sums. Two subjects, *M* and *W*, claimed that letters and sums were more difficult. This checks with results of both *W* and *M* in Series VI. *W*, who had a good place memory, memorized the pairs as they occurred consecutively in the series. He adhered to it throughout, despite the fact that the order was always changed in recall. The subjects, as a rule, used mnemonic devices and useful intermediaries more freely than in learning false capitals. For example, 12 + 14 = 28: the second number is one half of the false sum 28. *U* + *H* = 31, because *U* (ta) *H* is the 31st state! etc. Attention has been called to the fact that the normal constrained association time for true capitals and that for true sums were practically the same. The inhibiting power of the false capital is somewhat less, however. A false capital increases the normal association time by 2.002″, and a false sum increases the normal time by 2.168″. (Derived from Table VIII.)

(*c*) *The Association of False Authors in Literature.*—The same authors, arranged in the same series, were used here as with the groups; and, in addition, an extra series of unknown authors was prepared for use with the L.K. Lit.

Check Series I		Check Series II	
Kind Hart's Dream	Henry Chettle	Revoked Vengeance	Heard
Anne Hereford	Wood	The Country Ball	Praed
The Doome	Batman, etc.	Shadows on the Wall	Hewitt, etc.

The main purpose in using this material with individuals was to see if the results would check with those of the groups, showing that the less known literature was more inhibitive than the well known. The comparative strength of the two types, *i.e.*, W.K. Lit. and L.K. Lit., was sought in two ways: (1) By comparing the difference between the association time between W.K. Lit. and its check series (unk. lit.), with the difference that occurred between L.K. Lit. and its check series. (2) By combining the W.K. and L.K. types into a single series of 30, using the same false authors and determining again their association time. This latter procedure insured relatively uniform conditions in responding to the two series, and gave results that permitted direct comparison.

The limited current knowledge of both types of literature made it impractical to secure normal association time. It was attempted with uncertain results for the W.K. series, and to have required learning of the true authors would have changed the procedure from that employed with the groups. The seven subjects knew, on an average, 66 percent of the authors of the W.K. and 33 percent of the authors of the L.K. series. The entire procedure covered six periods given here in schematic form.

Period I Learning W.K. paired with check series	Period II Testing after 48 hours	Period III Learning (1 wk. later than Period II) L.K. paired with check series.
Period IV Testing after 48 hours	Period V (Wk. after Per. IV) W.K. paired with L.K. series	Period VI Testing after 48 hours.

TABLE IX

SHOWING REACTION TIME TO FALSE AUTHORS OF WELL AND LESS KNOWN LITERATURE AND TRUE AUTHORS OF UNKNOWN LITERATURE

Kind of Measure	When Well-known Literature Series Is Presented First (4 Subjects)					
	W.K. Paired with Unk. Lit.		L.K. Paired with Unk. Lit.		W.K. Paired with L.K. Lit.	
	Well-known	Unknown	Less Known	Unknown	Well-known	Less Known
Mean	3.084	2.492	2.520	1.728	2.628	1.992
Mean	1.576	1.684	2.088	1.624	1.788	1.944
Mean	2.252	1.996	1.324	1.164	4.768	2.008
Mean	7.128	2.816	4.244	4.792	1.228	4.956
Av. of Mean	3.510	2.247	2.544	2.327	2.603	2.725
Range	4.368	6.940	8.648	2.704	6.700	5.032
Range	2.556	2.144	5.204	1.692	1.780	7.120
Range	3.440	5.920	1.940	1.440	3.052	7.260
Range	21.168	6.664	6.520	4.720	9.920	8.636
Av. of Range	7.883	5.417	5.578	2.639	5.363	7.012
Median	3.120	2.080	1.800	1.364	1.790	1.734
Median	1.430	1.560	1.700	1.640	1.000	1.260
Median	2.120	1.440	1.248	1.064	1.640	1.460
Median	3.780	2.134	3.544	3.540	3.740	4.168
Av. of Median	2.612	1.803	2.073	1.902	2.042	2.155
P. E.	0.1126	0.1141	0.2531	0.0727	0.1701	0.1102
P. E.	0.0522	0.0463	0.1163	0.0444	0.0444	0.0187
P. E.	0.0964	0.1223	0.0390	0.0381	0.0722	0.1494
P. E.	0.1675	0.0479	0.0575	0.0306	0.0277	0.2245
Av. of P. E.'s	0.1071	0.0901	0.1164	0.0464	0.0786	0.1257
	When Less Known Literature Series Is Presented First (3 Subjects)					
Mean	2.088	2.072	2.152	1.332	1.740	1.524
Mean	2.224	1.448	1.812	1.464	1.732	1.460
Mean	2.332	1.568	2.681	2.092	1.504	1.224
Av. of Mean	2.214	1.696	2.216	1.629	1.658	1.402
Range	3.688	2.980	5.220	1.240	2.700	2.992
Range	6.268	1.540	3.312	1.532	5.588	2.404
Range	4.880	1.304	4.104	3.860	3.060	1.480
Av. of Range	4.942	1.941	4.212	2.210	3.782	2.292
Median	1.692	1.480	1.540	1.372	1.580	1.400
Median	1.680	1.660	1.816	1.540	1.420	1.180
Median	1.621	1.616	1.440	1.340	1.380	1.216
Av. of Median	1.665	1.585	1.598	1.417	1.460	1.265

TABLE IX—*Continued.*

Kind of Measure	When Less Known Literature Series Is Presented First (3 Subjects)					
	W.K. Paired with Unk. Lit.		L.K. Paired with Unk. Lit.		W.K. Paired with L.K. Lit.	
	Well-known	Unknown	Less Known	Unknown	Well-known	Less Known
P. E.....	0.1007	0.0846	0.1407	0.0249	0.7030	0.0653
P. E.....	0.0444	0.0364	0.0724	0.0342	0.1164	0.0578
P. E.....	0.1339	0.0327	0.0883	0.0900	0.0582	0.0324
Av. of P. E.'s.....	0.0930	0.0512	0.1004	0.0497	0.0816	0.0518

Four subjects learned W.K. Lit. first, and three, L.K. Lit. first. The results are given in Table IX. Differences between the averages of the means for the several paired types follow, also P.E.'s:

	I. When W.K. Lit. was Presented First:		
	(*a*) W.K. paired with Unk.	(*b*) L.K. paired with Unk.	(*c*) W.K. paired with L.K.
Difference of Means..	1.263″ excess W.K.	0.217″ excess L.K.	0.122″ excess L.K.
Difference of P.E.'s...	0.017″ excess W.K.	0.070″ excess L.K.	0.0471″ excess L.K.

(To be read: The average association time for responding with false authors of W.K. Lit. exceeds the average association time for responding with true authors to unknown literature by 1.263″.)

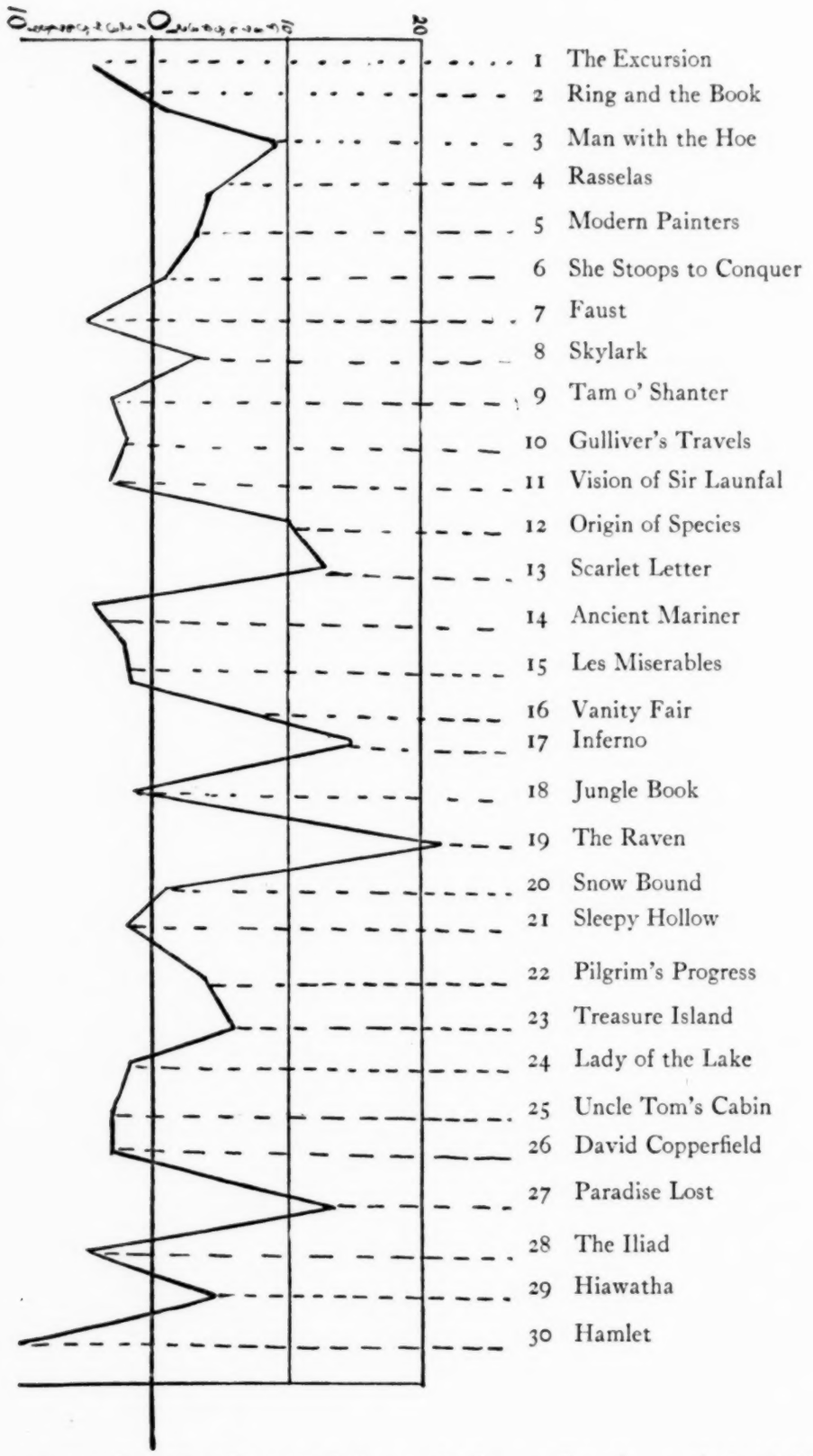
	II. When L.K. Lit. was Presented First:		
	(*a*) W.K. paired with Unk.	(*b*) L.K. paired with Unk.	(*c*) W.K. paired with L.K.
Difference of Means.	0.518″ excess W.K.	0.527″ excess L.K.	0.256″ excess W.K.
Difference of P.E.'s ..	0.0418″ excess W.K.	0.050″ excess L.K.	0.0298″ excess W.K.

This partial synopsis of Table IX. shows that when W.K. series is presented *first*, the difference in association time between W.K. and its check series is greater than that between L.K. and its check series; but when L.K. and W.K. are combined in the same series, L.K. shows the excess (see (*c*) above). When the L.K. series is presented first, results are reversed in the third combination (*c*), and W.K. means or averages are greater than those of L.K. The excess of L.K. over Unk. is more than doubled, while that of W.K. is less than half, this series giving the shorter association time as expressed by both means and medians. Whatever amount

of inhibition may be produced under the conditions, it is obscured by the effect of practice; and the question as to the relative inhibiting effects of W.K. and L.K. Lit. is left in doubt so far as this method of comparison is concerned.

A simpler and more direct method of comparison is found by using the quartile distribution of the association times. Recourse was had to the array of W.K. and L.K. established by the results obtained by working with groups, in which the two were combined into a single series according to the number of authors known. The average association time of seven subjects, responding with a false author to his associated literary work, was computed for the entire series of 30 literary works in the array. *The average in each case is based upon the responses of seven subjects.* The Excursion was first in the array and gave an average association time for seven subjects of .992″. Tam o' Shanter came ninth and gave 2.920″, and Hamlet came thirtieth or last with 0.892″. Then the averages of the association times for the first and fourth quartiles, and the middle half of the array were computed; the first quartile gave an average of 1.572″, the middle half 1.760″. While the differences in association time may be considered relatively small, I think they are fully large enough to be significant, and to afford unmistakable support to the results obtained from subjects taken in groups. Least known offer a *minimum* of inhibition, less, fairly or half known authors produce a *maximum*, while well-known authors give a *medium* inhibition. Or in general, the second type shows, that a maximum amount of inhibition is exerted in forming new bonds of connections between a new and an old experience when the latter has weak bonds with other experiences, while the third indicates that a medium amount is offered in forming new bonds of connections between an old and a new experience when the former has firm connections with other experiences.

These several degrees of inhibition are best expressed in Graph II. Here the amount exerted is measured by the difference in the association time for responding with a false author as shown by the mean for the seven individual subjects



GRAPH II. The distance of the graph above o line shows relative inhibiting strength of true author. o line is the normal association time for responding to true author of unknown literature.

and the mean of the association time for responding with a false author as shown by the mean for the seven individual subjects and the mean of the association for unknown authors based upon the grand total of responses of the seven subjects to the 30 unknown literary works. This latter association time was 1.975. It serves as the base of reference in Graph II. and is marked 'o.' If the association time for a false author was less than 1.975, the difference is indicated by the distance below the zero line, *e.g.*, the mean time for giving the false author of 'Excursion' is 1.528, or less than that of the mean for the unknown by 0.447. It is indicated in the graph as over four units below the base line. If the association time of the false author exceeds that of the mean of the unknown, the difference was regarded by that much as inhibition and is expressed by distance above the base line. The false author of Skylark gave an association time of 2.316 or greater than the mean of the unknown by .341.

Both the W.K. Lit. and L.K. Lit. are combined into an array as previously described and placed above the graph so that the name of each literary work falls directly over the point that measures the extent of its variation above or below the base line.

The graph affords, perhaps, the best device for showing the extent to which the results obtained from the individuals check those of the groups. The factors upon which the graph is based are too complex, however, to justify an explanation of its several irregularities, were it possible to do so.

Summary and Discussion

1. The results make it clear that the comparative difficulty of both State Capitals and Authors should have been determined prior to the investigation by testing at least 100 representative college students. This applies particularly to the authors. Had this been done, Faust, Gulliver's Travels, Origin of Species of the W.K. Lit. would doubtless have changed places with The Jungle Book, Sleepy Hollow, and Uncle Tom's Cabin in L.K. Lit. While this arrangement would hardly have changed the direction of the results, it would have increased their decisiveness.

2. The investigation shows that associative inhibition is an active principle in learning meaningful material, acting adversely for the most part, and that the amount of its action is determined by the relative strength of the association between the two elements involved.

3. If we measure the inhibiting strength offered by an author and his book, or any other associative material, according to the percentage of *group recall* or 'current knowledge,' then the degrees of strength can be expressed numerically. And from the present results we may obtain the following degrees of strength:

(*a*) If the bond is so weak as to be practically inoperative, having a recall power from 1 percent to 10 percent, and if one of the elements be somewhat familiar, then connecting the latter with a third element is favored by the associative condition (Excursion in Table VII. and Graph II.).

(*b*) If the connecting bonds give a recalling power of 15 percent to 40 percent, the inhibiting power is relatively small (She Stoops to Conquer, Table VII., also Graph II.).

(*c*) If the connecting bonds give a recalling power of 45 percent to 70 percent, the inhibiting strength approaches a maximum degree. Still, "a little learning is a dangerous thing."

(*d*) If the connecting bonds give a recalling power of 75 percent to 100 percent, the inhibition is of medium strength and in some cases may pass from an inhibiting to a facilitating rôle in learning (see Iliad, Hiawatha, and Hamlet, in Table VI. and Graph II.).

The two degrees of strength described in (*c*) and (*d*) are illustrated by new and old postal clerks in re-learning the distribution of a mail route after it has been broken up and re-formed into a new distribution. The clerk old in service re-learns and uses the new arrangement with greater ease and certainty than the new clerk of small experience. Of course the groups upon which the percentage of recall power is based should be homogeneous. The groups of this investigation have already been described.

4. The principle of inhibition in the higher association

processes grounds on the relative strength of the reacting complexes involved, or, in neural terms, it appears to depend on the difference of preparedness for discharge that may exist between rival neural centers. The functioning of the advantaged center, for whatever reason, precludes the functioning of its rival. A thoroughgoing theory of inhibition must account for (1) The difference in preparedness between the rival centers, so-called, (2) It must account for neural centers becoming rivals, or opposed to each other. Is this more or less paired opposition acquired or innate, or both? The present study indicates that it may be acquired, when involving high association processes.

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EFFECTS OF PRACTICE UPON THE SCORES AND PREDICTIVE VALUE OF THE ALPHA INTELLIGENCE EXAMINATION

BY FLORENCE RICHARDSON AND EDWARD S. ROBINSON

The University of Chicago

I. Subjects, Materials and Methods 300
II. Absolute and Relative Improvement 301
III. Consistency of Improvement Among Individual Subjects 307
IV. Effects of Practice on Functioning of Possible Critical Scores 308
V. Effects of Practice on Correlations Between Test Performances and Scholarship 310
VI. Causes of Improvement 314
VII. Summary 316

I. Subjects, Materials and Methods

The material upon which this report is based was derived from the examinations given a group of students who were used as controls in a study, shortly to be published, on the effects of loss of sleep.

Three forms of the alpha examination in the order 5, 7, and 9,[1] were given during a forenoon class period on three consecutive days, March 2 to 4 inclusive. These examinations were chosen on the assumption that they are well equated in difficulty, and that the scores of the different forms are comparable.[2]

The examinations were given on each day and scored in strict accordance with the instructions in use in the Army as

[1] Dunlap and Snyder (Jour. of Exp. Psych., Oct., 1920, Vol. III., pages 396–403) used forms of the alpha examination in the order 6, 8, 5, and 9, at intervals of 'approximately three weeks.'

[2] Since this paper was written the fuller account of the army results from the alpha examination has come to hand (*Memoirs of the National Academy of Sciences*, 1921, Vol. XV.). Data are presented here (p. 659, Table 174, and p. 660, Tables 176 and 177) which show the relative difficulty of these forms for random samplings of the white draft. The differences in the difficulty of the different forms according to these data are hardly great enough to alter to an important extent the results presented in this paper.

given by Yoakum and Yerkes.[1] The group was composed of thirty-nine college students, thirty-seven men and two women, most of them of sophomore standing and of an average age of 20.2 years. Of these, one had taken the alpha examination several years ago; he ranked thirty-first among our subjects on the first day's trial with a score of 144. Twenty-seven had taken the Thorndike Intelligence Tests for High School Graduates and College Students about sixteen months earlier; their average score on the first day's test was 160.9 as compared with the general average of 160.0. Six had taken the Thurstone Intelligence Test for High School Graduates, and their average score for the first day's test was 161.8. Six had taken no such test previously and their average score on the first day was 162.6. It seems likely that possible differences due to previous contacts with such test materials had little positive significance as practice on the scores of the first day.

The effects of practice are considered from the standpoint of *scores*, which represents the amount of credit given according to the army method of scoring the *right* responses, and of *attempts*, which represents the total number of items responded to, either correctly or incorrectly. Not enough work has been published comparing these two methods to justify the elimination of either in estimating the relation of one examination to another.

The statistical analysis of the results gives information of value to those who make practical use of the tests in college administration. It is interesting also to consider these scores as an example of practice in a complex function, and of the mechanisms by means of which positive and negative transfer operate under these specific conditions.

II. Absolute and Relative Improvement

Table II. presents the average scores for the three days of the experiment and also the relative achievements on days 2 and 3 as compared with day 1. According to the combined scores of all eight tests, day 2 shows a marked improvement over day 1, and day 3 a less marked improvement

[1] 'Army Mental Tests,' Yoakum and Yerkes, 1920, pp. 53–79.

TABLE I

EXAMINATION RECORDS OF INDIVIDUAL SUBJECTS

S—Score
A—Attempts

Subject	Day 1		Day 2		Day 3	
	Form 5		Form 7		Form 9	
	S	*A*	*S*	*A*	*S*	*A*
1	198	207	200	212	203	212
2	193	205	201	211	194	212
3	191	203	181	206	196	201
4	187	208	182	201	185	208
5	180	194	171	196	182	207
6	178	199	182	194	179	197
7	176	191	193	209	200	212
8	176	183	177	194	192	202
9	176	201	185	200	182	203
10	175	196	173	202	168	198
11	174	200	177	203	163	201
12	173	188	176	194	180	206
13	169	192	180	200	174	207
14	168	197	186	208	187	208
15	166	184	187	199	182	200
16	165	194	178	200	183	198
17	165	190	159	194	160	201
18	165	193	170	189	177	201
19	161	173	152	167	162	192
20	159	195	168	199	166	204
21	159	185	157	198	176	198
22	159	199	174	208	167	199
23	158	185	178	198	176	201
24	158	171	171	190	178	202
25	157	166	166	189	161	181
26	156	204	158	205	161	204
27	155	179	162	192	163	192
28	153	190	180	199	175	203
29	151	200	165	207	177	210
30	151	191	158	201	156	201
31	148	163	169	197	164	193
32	147	167	162	185	163	194
33	147	159	173	182	175	185
34	144	168	152	191	151	189
35	140	165	157	182	153	180
36	138	159	159	190	153	189
37	131	170	161	206	149	201
38	130	166	160	187	155	188
39	102	131	111	141	122	155

TABLE II

AVERAGE TEST SCORES AND RELATIVE ACHIEVEMENT ON SUCCESSIVE DAYS

Combined Records (All tests)

	Day 1	Day 2	Day 3
Average and S. D.	161.00 ± 18.63	170.51 ± 15.9	171.54 ± 15.2
Relative Achievement	100%	105.9%	106.5%

TABLE II—*Continued*

Test 1, Oral Directions

	Day 1	Day 2	Day 3
Average and S. D.	10.13 ± 1.35	11.46 ± 0.62	11.49 ± 0.70
Relative Achievement	100%	113.1%	113.4%

Test 2, Arithmetical Problems

	Day 1	Day 2	Day 3
Average and S. D.	12 79 ± 2.50	14.62 ± 2.35	15.67 ± 2.73
Relative Achievement	100%	114.3%	122.5%

Test 3, Practical Judgment

	Day 1	Day 2	Day 3
Average and S. D.	12.36 ± 2.67	13.49 ± 2.08	14.21 ± 1.21
Relative Achievement	100%	109.1%	114.9%

Test 4, Synonym-Antonym

	Day 1	Day 2	Day 3
Average and S. D.	30.41 ± 5.91	29.74 ± 5.54	30.79 ± 5.02
Relative Achievement	100%	97.8%	101.2%

Test 5, Disarranged Sentences

	Day 1	Day 2	Day 3
Average and S. D.	19.08 ± 3.48	21.51 ± 3.26	19.69 ± 3.29
Relative Achievement	100%	112.7%	103.2%

Test 6, Number Series Completion

	Day 1	Day 2	Day 3
Average and S. D.	12.79 ± 2.49	13.85 ± 2.80	15.36 ± 2.69
Relative Achievement	100%	108.3%	120.1%

Test 7, Analogies

	Day 1	Day 2	Day 3
Average and S. D.	29.82 ± 5.46	34.95 ± 3.18	32.90 ± 4.83
Relative Achievement	100%	117.2%	110.3%

Test 8, Information

	Day 1	Day 2	Day 3
Average and S. D.	33.69 ± 3.7	30.92 ± 4.1	31.44 ± 3.9
Relative Achievement	100%	91.8%	93.3%

TABLE III

AVERAGE ATTEMPTS AND RELATIVE ACHIEVEMENT ON SUCCESSIVE DAYS

Combined Records (All Tests)

	Day 1	Day 2	Day 3
Average and S. D.	184.89±16.82	195.54 ± 11.6	198.33±10.44
Relative Achievement	100%	105.8%	107.3%

Test 1, Oral Directions

	Day 1	Day 2	Day 3
Average and S. D.	12.0 ± 0	12.0 ± 0	12.0 ± 0
Relative Achievement	100%	100%	100%

Test 2, Arithmetical Problems

	Day 1	Day 2	Day 3
Average and S. D.	15.13 ± 2.26	16.36 ± 1.93	17.18 ± 2.28
Relative Achievement	100%	108.1%	113.6%

Test 3, Practical Judgment

	Day 1	Day 2	Day 3
Average and S. D.	13.31 ± 2.50	13.74 ± 2.15	15.44 ± 1.18
Relative Achievement	100%	103.2%	116.0%

Test 4, Synonym-Antonym

	Day 1	Day 2	Day 3
Average and S. D.	35.54 ± 5.58	36.18 ± 4.06	37.74 ± 3.52
Relative Achievement	100%	101.8%	106.2%

Test 5, Disarranged Sentences

	Day 1	Day 2	Day 3
Average and S. D.	21.92 ± 2.50	23.62 ± 1.05	23.31 ± 1.40
Relative Achievement	100%	107.7%	106.3%

Test 6, Number Series Completion

	Day 1	Day 2	Day 3
Average and S. D.	14.87 ± 2.58	16.08 ± 2.62	17.05 ± 2.18
Relative Achievement	100%	108.1%	114.7%

TABLE III—*Continued*

Test 7, Analogies

	Day 1	Day 2	Day 3
Average and S. D.	34.00 ± 4.90	38.69 ± 2.80	36.31 ± 3.76
Relative Achievement	100%	113.8%	106.8%

Test 8, Information

	Day 1	Day 2	Day 3
Average and S. D.	38.13 ± 4.08	38.90 ± 3.96	39.31 ± 1.60
Relative Achievement	100%	102.0%	103.1%

over day 2, *i.e.*, progress due to practice is, within the limits studied, negatively accelerated.[1,2] Variability as measured by the standard deviation decreases roughly in inverse proportion to improvement.

[1] Yoakum and Yerkes (*op. cit.*, p. 50) state that the average gain in a repeated alpha examination is approximately 8 points (raw score). If this gain refers to the gain of a second testing over a first, it is approximately substantiated by our results which show a gain of 9.47 points with this sort and amount of practice.

[2] If we should correct the average scores for these three days in light of the data presented in the *Memoirs*, Vol. XV., our facts would be little altered. No accurate correction can be derived for our results, however, from the army data which are based upon the random samplings of the white draft. Whereas the average scores of that group in the different forms range from 60.85 to 66.81, the average score for our group before practice begins to take effect is 161.07. It would hardly be legitimate to conclude that differences in the difficulty of different forms as shown by the performances of a group whose average performance is 60–67 would hold for a group whose average performance is 160 or better.

In order to estimate the relative difficulty of forms 5, 7, and 9 (the forms employed in our study) in the upper ranges of intelligence, we computed the average performances with these forms by those of the white draft whose scores were 100 or better (our lowest score was 102). According to the army data from the complete samplings, form 7 is 2.44 points more difficult than form 5 and form 9 is 3.47 points more difficult than form 7, while according to our selections of the more intelligent members of the white draft, form 7 is 1.00 easier than form 5, and form 9 is 4.20 more difficult than form 7. While our sampling of the more intelligent members of the white draft is done in quite arbitrary fashion, it is perhaps fair to judge from it that forms 5 and 7 are practically of equal difficulty for groups of a high degree of intelligence and that form 9 is about 4 to 5 points more difficult than form 7.

It is probable, then, that the amount of improvement from day 1, form 5, to day 2, form 7, as shown in Table II. is much more a matter of practice than of the relative difficulties of the two forms. Since form 9, which was employed on day 3, is almost certainly more difficult than form 7, which was employed on day 2, the improvement in ability of day 3 over day 2 is probably somewhat greater than is shown by the averages of our table and, yet, somewhat less than the improvement of day 2 over day 1.

Considering the separate tests, four of these (1, directions; 2, arithmetical problems; 3, practical judgment; and 6, number series completion) show continuously increasing averages throughout the experiment. Progress in the other four tests (4, synonym-antonym; 5, disarranged sentences; 7, analogies; and 8, information) is less regular. But only in test 8 was the highest average score obtained on day 1.

The greatest effects of practice are shown by tests 2 and 6. In the case of test 4 there is no appreciable improvement and in test 8 there is clearer evidence for a falling off in efficiency than for improvement.

Table III. presents the average number of points, problems or questions toward which the subjects gave a response which was either correct or incorrect, and also the relative achievement by this attempts criterion. According to the records of all the tests combined, Table III., like Table II., shows a considerable improvement for day 2 over day 1 and a less marked improvement for day 3 over day 2. As in the case of scores, variability decreases roughly in inverse proportion to improvement.

Five of the tests (2, arithmetical problems; 3, practical judgment; 4, synonym-antonym; 6, number series completion and 8, information) show an increasing number of points attempted throughout the experiment. Test 1, directions, shows neither positive nor negative practice effects. Positive effects would have been impossible in this case, due to the fact that the maximum number of attempts was made in the first day's performance. In the case of test 5, disarranged sentences, more attempts were made on day 2 than on day 3, but this difference is hardly significant. In test 7, analogies, there is a considerable superiority for day 2 over day 3. In no test, however, was the greatest number of attempts made on day 1.

Considering the evidence presented by all of our averages, then, the main trend is toward an improvement for day 2 over day 1, and somewhat less improvement for day 3 over day 2.

III. Consistency of Improvement among Individual Subjects

The inspection of Tables II. and III. demonstrated that, while in general there is a continuous improvement throughout the three days of the experiment, certain individual tests do not agree with our findings as a whole. Tables IV. and V. give the numbers of subjects, who, according to *scores* and *attempts*, improved continuously, lost continuously, or varied in achievement in some less regular fashion.

Table IV

Scores

3 means that this day's performance was lower than that of the other two days.

2 means that this day's performance was lower than that of one other day and higher than that of the other.

1 means that this day's performance was higher than that of the other two days.

Day 1	Day 2	Day 3	Number of Individuals Giving Days This Rank Order
3	2	1	14
3	1	2	17
2	3	1	4
2	1	3	1
1	2	3	1
1	3	2	2
Total.....	.....	.....	39

Table V

Attempts

3, *2*, and *1* have same meaning as in Table IV.

Day 1	Day 2	Day 3	Number of Individuals Giving Days This Rank Order
3	2	1	17
3	1	2	9
2	3	1	3
2	1	3	1
1	3	2	1
2.5	1	2.5	2
1.5	3	1.5	1
3	1.5	1.5	5
Total.....	.....	.....	39

Considering *scores* (Table IV.), the order 3–2–1, which

stands for continuous improvement, is represented by fewer individuals than the order 3–1–2 which stands for initial improvement followed by a loss. There is only one subject, however, who shows a continuous loss throughout the experiment, and a decided majority (31 out of 39) of the subjects do better on both day 2 and day 3 than on day 1. Variations from the condition of continuous improvement are, therefore, due largely to the likelihood of day 2 showing a better performance than day 3. This is in accordance with the conclusion, based upon the averages of Table II., to the effect that the difference between day 1 and day 2 is probably greater than that between day 2 and day 3.

Considering *attempts* (Table V.), we find similar facts. The condition of continuous improvement here, however, is clearly most frequent. No subject shows a continuous loss, and again 31 out of 39 do better on days 2 and 3 than on day 1. These data further verify the generalization that practice in taking these tests is associated with improvement in achievement, especially of the second testing over the first.

IV. Effects of Practice on Functioning of Possible Critical Scores

The facts of improvement due to practice have so far been described in terms of changes in average improvement and in terms of the number of individuals whose achievement follows or varies from the general tendency of the group. For practical purposes it will be well to consider the specific effects which changes due to practice have upon the predictive value of the alpha examination. If, for example, *critical scores* for exclusion or selection were set on the basis of the group's performance on day 1, it would be of practical significance to note the effects of given amounts of practice upon the likelihood of such scores retaining their original exclusive or selective efficiency.

If, in terms of *scores*, that critical score had been selected upon the basis of the first day's records which would have separated the lower 9[1] from the upper 30 individuals, the

[1] The hypothetical critical scores which we shall discuss have been set to exclude the lowest 9 subjects or to select the 9 highest, except where there was a tie at the 9th

application of this critical score to the records of days 2 and 3 would have resulted in the exclusion on both days of only one individual, he being the same on both occasions. If a lower, or *exclusive*, critical score had been set on the basis of the records of day 2 so that the lowest 9 subjects on that day would have been excluded, the application of that score to the records of day 3 would have resulted in the exclusion of 7 subjects, 5 of whom belonged to the lowest 9 of day 2.

Similar results would have been obtained had lower critical scores been based on *attempts*. A score which would have excluded the lowest 9 on the first day would, if it had been applied to the second day's records, have excluded 2 individuals, but 1 of whom belonged to the originally excluded 9. Applied to the records of day 3, this critical score would have excluded only 1 individual.

Returning again to a consideration of *scores*, if an upper critical score had been set which would have selected the highest 9 subjects on day 1, that same score would have selected 16 subjects on day 2 and 18 subjects on day 3. If a critical score had been set which would have selected the highest 9 subjects on day 2, that score would have selected 11 subjects on day 3.

If *attempts* had been taken as the criterion and a critical score set which would have selected the highest 10 subjects on day 1, that score would have selected 19 subjects on day 2 and 24 subjects on day 3. If a critical score had been set which would have selected the highest 10 subjects on day 2, that score would have selected 13 subjects on day 3.

We may conclude from these facts that the changes in achievement due to even a small amount of practice, *i.e.*, that represented by taking the examination once, may largely invalidate the functional significance of a critical score based upon the records of a group having had little or no previous experience with the alpha examination. Since our evidence points to an early negative acceleration in the progress due

rank, in which case the critical score was set to exclude the lowest 10 or select the highest 10. These points have been chosen arbitrarily, of course, but they fall between the twenty-third and twenty-sixth percentile in the case of the lower one and between the seventy-fourth and seventy-fifth percentile in the case of the upper one.

to practice,[1] critical scores set after a group has had even a small amount of practice will probably maintain their significance fairly consistently for groups having had as much or more practice. This generalization is supported by the results of our application of critical scores based on second-day records to third-day results, and it lends support to the suggestion of Dunlap and Snyder[2] that if tests susceptible to practice are used, all candidates should have old forms of the test in advance. How much fore-exercise the candidates have is probably not so important as the fact that they should have some fore-exercise.

V. Effects of Practice upon Correlations Between Test Performances and Scholarship

The 39 subjects of our experiment were rated according to their scholarship records for five quarters, or one and two thirds college years. In Table VI. there are presented the values of

$$\rho\left(\rho = 1 - \frac{6\Sigma D^2}{n(n^2 - 1)}\right)$$

between the examinations of different days, and combinations of days, and scholarship. Where records of different days are combined, this was done in terms of ranks so as not to give extra weight to the performance on days most benefited by practice.

Table VI

	ρ	P.E.
Scores		
Day 1 and Scholarship	.56	.07
Day 2 and Scholarship	.65	.06
Day 3 and Scholarship	.62	.07
Days 1 and 2, and Scholarship	.60	.07
Days 1 and 3, and Scholarship	.63	.07
Days 2 and 3, and Scholarship	.66	.06
Days 1, 2, and 3, and Scholarship	.64	.07
Attempts		
Day 1 and Scholarship	.41	.09
Day 2 and Scholarship	.32	.10

[1] The sharpness of this negative acceleration is somewhat doubtful according to our results, because of the impossibility of accurately determining the relative difficulties of forms 7 and 9, the forms used on the second and third days respectively.

[2] *Op. cit.*, p. 402.

Day 3 and Scholarship	.37	.09
Days 1 and 2, and Scholarship	.37	.09
Days 1 and 3, and Scholarship	.37	.09
Days 2 and 3, and Scholarship	.35	.10
Days 1, 2, and 3, and Scholarship	.37	.09

A consideration of the values in this table brings out the following facts:

1. There are noticeably higher correlations between *scores* and scholarship than between *attempts* and scholarship.

2. The differences between the coefficients secured on the different days of the testing are practically negligible. There is just a slight chance that the second or third day's examination, so far as *score* is concerned, has higher predictive value than that of day 1.

3. No significant increase in predictive value occurs when the test records of two or three days are combined.

In the previous section we considered the effects which one or two practice sittings would have upon the efficiency of a critical point set at some absolute score. It is also interesting to consider the relative eliminative or selective efficiency of certain critical ranks. Tables VII., VIII., IX. and X. present data bearing upon this point. Due to the comparatively low correlations between *attempts* and scholarship, these data are concerned only with scores.

Table VII

Students ranking from 33 to 39 inclusive in scholarship have grades which render them liable to elimination from college. Students having these ranks (33 to 39) in the tests of the different days and combinations of days have the following ranks in scholarship.

Days	Scholarship Ranks of Students Ranking from 33 to 39 in Tests
1	13.5, 28, 31, *33*, *37*, *38*
2	15, 20, 31, *33*, *34*, *38*, *39*
3	13.5, 28, 31, *33*, *37*, *38*, *39*
1 and 2	13.5, 28, 31, *33*, *37*, *38*, *39*
1 and 3	13.5, 28, 31, *33*, *37*, *38*, *39*
2 and 3	20, 28, 31, *33*, *37*, *38*, *39*
1, 2, and 3	13.5, 28, 31, *33*, *37*, *38*, *39*

TABLE VIII

Students ranking from 1 to 6 inclusive in scholarship have grades which render them eligible for *honors*. Students having these ranks (1 to 6) in the tests of the different days and combinations of days have the following ranks in scholarship.

Days	Scholarship Ranks of Students Ranking from 1 to 6 in Tests
1	*1*, *5.5*, 7, 8, 13.5, 22
2	*4*, *5.5*, *5.5*, 7, 16, 23.5
3	*3*, *4*, *5.5*, 7, 8, 23.5
1 and 2	*1*, *5.5*, 7, 8, 22, 23.5
1 and 3	*1*, *3*, *5.5*, 7, 8, 23.5
2 and 3	*4*, *5.5*, *5.5*, 7, 8, 23.5
1, 2, and 3	*1*, *5.5*, 7, 8, 16, 23.5

TABLE IX

Students ranking from 33 to 39 inclusive in scholarship have grades which render them liable to elimination from college. Students of this group are ranked as follows by the tests of the different days, and by combinations of days.

Days	Test Ranks of Students Ranking from 33 to 39 in Scholarship
1	17, 21, 21, 29.5, *34*, *36*, *39*
2	24, 31.5, 31.5, *33.5*, *35.5*, *37.5*, *39*
3	17.5, 24, 32, *33*, *35.5*, *37.5*, *39*
1 and 2	22, 23, 29.5, *33*, *35*, *38*, *39*
1 and 3	19, 22.5, 26, *33*, *35*, *36*, *39*
2 and 3	24.5, 26, 30, *33.5*, *35.5*, *38*, *39*
1, 2, and 3	22, 25, 27.5, *33*, *35*, *38*, *39*

TABLE X

Students ranking from 1 to 6 inclusive in scholarship have grades which render them eligible for *honors*. Students of this group are ranked as follows by the tests of the different days and combinations of days.

Days	Test Ranks of Students Ranking from 1 to 6 in Scholarship
1	*1*, *4*, 8, 14, 15, 17
2	*2*, *4*, *5*, 7.5, 12.5, 14.5
3	*1*, *5*, *6*, 7, 8, 10
1 and 2	*1.5*, *4*, 8.5, 8.5, 10, 16
1 and 3	*1*, *5*, *6*, 10, 12.5, 12.5
2 and 3	*1*, *4*, *6*, 7, 9, 10.5
1, 2, and 3	*1*, *5*, 7, 9, 10, 12

According to the present interpretation of scholarship records by the administration of this college, students whose

grades are as low or lower than those of the lowest 7 members of our group are eligible for dismissal. For practical purposes one might, in light of this fact, set a critical rank in test performance which would separate the lowest 7 individuals from the group as a whole.[1] Table VII. shows what are the ranks in scholarship obtained by the 7 individuals who are lowest according to the examinations of the different days and combinations of days. Only 6 individuals are considered in the case of day 1, because of a tie at the critical rank.

None of the differences between these test measures is large enough to justify any confident statement of superiority for particular days or combinations of days. There is a slight chance that day 1 is not quite as good a selective agency as the other days, which apparently are of equal value.

Those students of our group ranking from 1 to 6 inclusive in scholarship have grades which render them eligible for *honors*. If we were interested in selecting honor students, we might set an upper critical rank which would select the best 6 members of the group. Table VIII. shows what scholarship ranks are held by those individuals who are included in the best 6 by the tests of different days and combinations of days. There is here a slight chance that day 1, days 1 and 2 combined, and days, 1, 2, and 3 combined are less efficient than day 2, day 3, days 1 and 3 combined, and days 2 and 3 combined, but these differences again may easily be due to chance.

Tables IX. and X. show the test ranks according to the different days and combinations thereof of the lowest 7 and the highest 6 individuals according to scholarship. In other words, they show which individuals would have been eliminated who, according to scholarship, should have been eliminated, and which individuals would have been marked for *honors* who should have been so marked. These results, like those of Tables VII. and VIII., give little ground for choice among the different test measures.

[1] It is theoretically possible that better results might be achieved by dividing the group at a point slightly above or below this one.

VI. Causes of Improvement

An effort to analyze the different factors which may have influence in accounting for the variability with practice reveals a high degree of complication. Various intellectual and emotional changes, and changes in method must be considered, along with such an external influence as the increase in time afforded by the fact that the subjects may neglect most of the instructions given by the examiner on the second and third days.

This extra time available during the second and third tests may be an important factor in determining the cause of an *apparent* practice effect. Excepting test 1, oral directions, where the instructions are given for the different items consecutively, the total time for all of the tests (2–8) is 20 minutes. The instructions, as read to this group, consumed a total of 4′ 38″ or 23.1 per cent. of the time allowed for work. When given according to the manual, the subject looks at the directions at the beginning of each test as the examiner reads them aloud. At the time of the first trial the subject is engrossed in the instructions; on the later trials, he is likely to feel so familiar with them, that he has the reading time free to dispose of otherwise. This added 23 per cent. of his gross time may be used in working ahead mentally on the actual test before him, so that he is well on his way when the signal to begin is given. When this time was not used as additional work time, it was often taken as a relaxation period. In introspective reports on the effects of practice, about one third of those reporting explicitly on this added time, spoke of taking it wittingly as a recuperative period. About two thirds used it for work.

This additional time might well be taken into account and controlled when similar tests are repeated. The plan was considered of reading the directions, on the later days, before the subject was permitted to turn the page to the approaching test. That would have meant, however, the substitution of indicated rest intervals amounting to nearly one fourth the time spent on the tests on the first day. An alternative of omitting, after the first examination, the reading of the direc-

tions would have meant reducing the gross time for the seven tests from about twenty-five minutes to a little more than twenty, allowing for time consumed in turning pages. This seemed inadvisable, as it introduced a change in method, the effect of which could not be estimated.

An important practice effect, as *practice*, seemed to be due to the development of method during and after the first day's work and its carrying over to later work. Many students spoke of a 'systematization' that was advantageous in some of the tests, particularly in test 2, arithmetical problems, and test 6, number series completion, which show continuously increasing average scores from day to day. The methods employed, in the case of test 6, were the same in succeeding problems on different days, so that each day's work pushed the frontier of progress a little further down the page. It was to this frontier that a number of students devoted themselves during the reading of the directions on days 2 and 3. This increase in effectiveness in working due to the development of method probably characterizes every test employed in alpha, although in some cases as in test 8, information, the method may largely be concerned with such activities as the eye-hand coördinations involved in crossing out words.

Another important factor was the change, on days 2 and 3, in the attitude toward the tests. This worked in two ways. The first effects, the disappearance of nervousness and anxiety, and the establishment of confidence were all conducive to an increase in score. The second effects were overconfidence, loss of interest and explicit boredom which in a number of cases were related to a decrease in the scores for the third day as compared to day 2. The general appearance of the class indicated this lack of interest in the third test.

Some transfer effect was of an intellectual sort, notably the increase in ability, in test 5, disarranged sentences, to take in at a glance the meaning of the sentence. A part of this perceptual factor may be accounted for as a method. The memory of earlier solutions in the arithmetical problems also carried over.

The high percentage of improvement in test 6, number series completion, second only to that in test 2, arithmetical problems, is doubtless due to the partial identity of the test materials in any two forms of alpha. In taking test 6 (form 7) on the second day the subjects found, in five of the twenty items, numbers of the same sequential series, *e.g.*, 2, 3, 4, 5, 6, 7, but beginning in a different point in the series, *e.g.*, 3, 4, 5, 6, 7, 8. In the remaining 15 items he found different *numbers*, but the same *methods* of completion, *e.g.*, 8, 1, 6, 1, 4, 1, and 9, 1, 7, 1, 5, 1. On the third day, all of the 20 items were identical with items of the two previous days and presented no new material.

This fact, of course, indicates a difficulty in equating different forms of such tests, due to the types of material used.

There was also some indication of added practice due to discussions between the examinations on various days. This discussion concerned itself with methods of solving arithmetical problems, and with verifications of answers in the information test, as, for instance, the apparently controversial point as to the number of a Zulu's legs. Here the dictionary and the encyclopedia contributed a basis for estimating the biological classification of the Hottentot and the Papuan.

The fact that absence of improvement, or even loss, sometimes occurs is probably due to the facts that the different forms of the alpha examination were equated as wholes and not part with part, and that in the case of some parts of the test the subject either has or has not the information necessary for a correct response; *i.e.*, some parts of the test are informational rather than problem solving in nature.

VII. Summary

1. Practice effects in the alpha examination administered in different forms to college students on three successive days show a marked improvement for day 2 over day 1 and probably a less marked improvement for day 3 over day 2. This result is an average tendency rather than a universal characteristic of all parts of the test and of the records of all subjects.

2. The amount of practice represented by one experience with the alpha examination largely invalidates critical scores

of a given selective or exclusive significance set upon the basis of a first performance with this test. Critical scores set upon the basis of a second performance are more likely to maintain their functional significance in the face of further practice.

3. Performance according to *scores* in all cases correlates more highly with scholarship than performance according to *attempts*.

4. There are no very important differences between the test-scholarship correlations for the different days or combinations of days. The *scores* of day 1 give the least accurate prediction of scholarship, but this inferiority may easily be due to chance.

5. Improvement is due to an increase in available time on succeeding tests due to the possible disregard of instructions; to an increase in motor facility; to development of methods; to shift in emotional attitude; to a transfer in perceptual factors; to identity of materials in the several forms, and to outside discussion of various points between examinations.

THE TASTE SENSITIVITY OF AN ANOSMIC SUBJECT

BY A. R. GILLILAND

Dartmouth College

When one of the special senses is missing or lost is there compensation in closely related senses? This question has received much theoretical consideration but little exact experimental study. A recent class demonstration of the importance of smell in so-called taste sensations brought out the fact that one member of the class had no sense of smell. A freshly cut piece of onion held to his nose was undetected so long as the eyes were closed. Experiments in chemistry were sometimes very difficult but the subject was generally able to make use of other means than smell for detecting chemical differences. In fact he did his work so well that his instructor did not know that the student was anosmic. The anosmic condition has been present from birth.

Such a subject presents an opportunity for a study of two interesting problems: (1) Is there compensation in two such closely related senses as taste and smell when one of these is lacking? If there be compensation of function, at least other than that resulting from increased exercise of the remaining parts or functions, it would seem likely to be present in two such closely related senses as these. (2) Whether or not there be compensation, is there any greater relative capacity to detect complex tastes by the sense of taste alone for such a subject? That is, will the greater reliance on taste by the anosmic make him able to detect different foods better than the normal subject when not using the sense of smell?

Solutions of cane sugar, quinine, tartaric acid, and sodium chloride, approximately four times the strength of the limens reported by Baily and Nicols[1] were prepared, for preliminary

[1] 'The Delicacy of the Sense of Taste,' *Nature*, XXXVII., 1887–88, 557.

experiments for determining the limen for each of the four primary tastes. The solutions were placed in tumblers on a table. The subject sat with his back to the table so that he did not know what substance was being given to him. The order of presentation was unknown to the subject. The experimenter gave the subject a teaspoonfull of the substance and the subject reported the taste. Five trials for each solution were made with as many added trials of ordinary tap water. This made forty trials in each experiment, twenty for water and five for each of the four solutions. The liquids were all of ordinary room temperature, about 30 degrees Centigrade. Four subjects took the experiment, the anosmic and three control subjects.

The original solutions were found to be entirely too strong. In all, twenty trials were made, five for each subject, before the best limen for each solution was determined. The results for the last six experiments are presented in Tables I. and II. The first table gives the responses and the scores for three subjects with the following strengths of solutions.

Sour (tartaric acid)	1 part in	25,000 parts of water
Bitter (quinine)	1 part in	300,000 parts of water
Salt (sodium chloride)	1 part in	6,250 parts of water
Sweet (cane sugar)	1 part in	320 parts of water

The second table gives the results for three subjects with salt 1 part in 9,375 parts of water instead of the strength given above. The other solutions were the same strength as before. This proved to be very near the limen for these three subjects and probably nearer the limen for the other subject who did not try this series of tests.

The scores given are for correct responses. If the subject was certain that he tasted one of the primary tastes he reported which one it was. If he did not taste anything in the liquid he reported the taste as water. Very often the subject was not certain. He sometimes reported that it was probably one or another of the substances or that it was possibly one of them. Such reports were not credited even if correct. Only unequivocally correct responses were scored.

TABLE I

Stimulus	Strength	Subject* W	Score	Subject* P	Score	Subject* G	Score
ACID (Tartaric)	40/1000000	bitter bitter acid acid acid	3	water bitter water bitter bitter	0	wate acid acid acid? bitter	2
BITTER (Quinine)	3⅓/1000000	acid water acid acid? sweet	0	salt salt bitter acid acid	1	bitter ??? bitter water water	1
SALT (NaCl)	160/1000000	water? salt salt salt salt	4	salt salt acid salt salt	4	salt salt salt salt salt	5
SWEET (Sugar)	3125/1000000	sweet sweet sweet bitter sweet	4	sweet water sweet sweet sweet	4	water water sweet water sweet?	1
WATER		water bitter water water water water acid? water bitter water sweet? water bitter? acid bitter water? sweet acid water? salt	8	water water water water water water salt water water water water water water bitter acid water water water water water	17	acid° water water water something water bitter? sweet salt? water water bitter water water water water water water water	14
		Total Score	19		26		23

TABLE II

Stimulus	Strength	Subject* *W*	Score	Subject* *M*	Score	Subject* *G*	Score
ACID (Tartaric)	40/1000000	sweet? bitter? acid water sweet	1	water bitter acid? acid bitter	1	sweet water bitter? water bitter	0
BITTER (Quinine)	3⅓/1000000	water water bitter water acid	1	bitter bitter bitter acid bitter	4	water bitter water water water	1
SALT (NaCl)	107/1000000	bitter acid salt bitter salt	2	salt water salt? salt salt?	2	water salt water water salt	2
SWEET (Sugar)	3125/1000000	salt? water sweet water salt	1	water sweet? water a taste water	0	sweet water salt sweet sweet	3
WATER		bitter water water acid salt acid sweet water water sweet? water water water bitter water sweet bitter acid water acid	9	water water water water water water water water salt water water water acid water water water water water water water water	18	acid? water water water acid bitter? bitter water bitter? water sweet water water water water water water water water water	14
		Total Score	14		25		20

Very often water was reported as having a taste. Distilled water was used at first but it seemed to prove more objectionable than tap water. With either it was impossible to eliminate this difficulty except with one subject who almost invariably reported water correctly. The anosmic subject reported a taste or a possible taste incorrectly for water more than half the time. For this reason water was used as a control as many times as all the other substances combined. The total possible score, one point for each correct response, was therefore 40.

The problem of fatigue of the end organs during the experiment was not so serious as might have been expected. When the limen of sensitivity was approached the different substances were so weak that their after effects were very small. The mouth was thoroughly rinsed several times during the experiment, at least once after each report of a definite taste. The frequent use of water as a control also helped to keep the mouth thoroughly cleansed. The fact that the latter part of the experiment contained as many correct responses as the first part is evidence that fatigue was not an important distracting element in the experiment.

The results show that the anosmic subject, *W*, was less able to detect the four primary tastes than any of the normal subjects. In the three records of Table I. the anosmic subject's score was 19 while one of the subjects, *G*, made 23 and the other, subject *P*, made 26. In Table II. subject *W*, the anosmic, made a score of 14; subject *G* made 20; and subject *M* made 25.

There is not a complete agreement in the scores of the same subject in the two tables. At least one cause besides accidental variation tended to produce this difference. In the first set of tests the salt solution was clearly above the limen. This not only improved the score for salt but left less chance for error with the three remaining primary tastes. The subject's procedure when the solution was very weak, was at least partly one of elimination:—first is or is not the substance one of the primary tastes? Second, if so which one is it? In the first set of experiments both the first and

second judgments were rendered easier because salt was readily eliminated as a possible taste. It was always clearly present or absent.

When the solutions were very weak it became largely a matter of judgment from a large number of external and internal factors. It was surprising how eagerly the subjects grasped for any possible clue for trying to detect the taste. It was necessary that the liquids all be of the same temperature. The experimenter had to be especially careful not to strike the tumblers with the spoon as the direction of the sound was immediately used by the subject as a cue in trying to differentiate the tastes. The order of presenting the different liquids also had to be very carefully worked out so as to allow the least possible chance for the subject's guessing the order.

We have considered the limen as the point at which the judgments were just perceptibly better than might be expected by the theory of chance. We might have chosen the point at which no errors in report were made or some other per cent. of success.

Since the different subjects did not have exactly the same limen for each of the primary tastes the strengths given in Table II. is approximately an average of the limens for the four subjects. Subject *M* probably could have detected bitter in a weaker solution. Subjects *P* and *G* might have reduced the limen for sweet but their two records do not show enough consistency to warrant a much greater reduction. Our final results do not differ greatly from the limens given by Baily and Nicols.[1]

Our second problem was to determine whether the anosmic subject could distinguish complex tastes—ordinary foods—better than a normal subject using the sense of taste alone. Seven raw foods were selected for the experiment—cabbage, apple, Irish potato, sweet potato, onion, carrot, and turnip. The anosmic and ten other students acted as subjects in this part of the experiment. The subjects sat with their back to the table containing the foods. Each food was presented

[1] *Op. cit.*

five times to each subject. Just as the particle of food was being presented to the subject he closed his nostrils with his fingers and locked his breath by filling the nasal cavity with air. In this condition practically no odor could reach the olfactory area so long as the subject held his breath. The subject was allowed to chew the substance as he would do in eating but was cautioned to hold his breath until his report was given.

The same method of scoring was used as described in the first experiment. The total possible score was 35. Table III. gives the responses and scores for the eleven subjects.

In order to be sure that unfamiliarity with taste of the seven foods since some of them are seldom tasted except when cooked a supplementary experiment was conducted with the anosmic and three other subjects. Five common raw foods were selected—orange, grapefruit, pineapple, tangerine, and tomato. Five trials were used for each. Out of a possible score of 25 the anosmic subject made 18, another 18, and the other two 21 each. The relative scores for each subject was practically the same as in the preceding experiment.

These results show that the anosmic subject was not better than the average normal subject; in fact not quite as good as the average for eleven cases. The much greater experience of the anosmic did not result in his ability to distinguish different kinds of complex tastes better than normal subjects using the sense of taste alone.

Conclusions

So far as we may generalize from the results of a single case there is no greater sensitivity to the primary tastes with an anosmic subject to compensate for the lack of the sense of smell.

The anosmic subject had no greater ability in detecting the complex tastes than the normal subject when using the sense of taste alone.

These results tend to disprove rather than prove a theory of the compensation of function.

TABLE III—*Continued*

Stimulus / Subject	Response											
	W (Anosmic)	P	C	M	J	S	Cs	Me	G	Py	H	Sn
CABBAGE	turnip? carrot cabbage cabbage turnip	carrot carrot cabbage carrot cabbage	apple cabbage cabbage turnip onion	onion cabbage cabbage cabbage S. potato	onion cabbage cabbage S. potato S. potato	cabbage cabbage turnip cabbage turnip	apple cabbage turnip cabbage cabbage	cabbage ??? I. potato ??? cabbage	cabbage cabbage cabbage onion cabbage	cabbage carrot cabbage cabbage cabbage	cabbage cabbage cabbage cabbage cabbage	onion cabbage cabbage cabbage cabbage
APPLE	apple apple apple apple apple	apple potato apple apple turnip	apple turnip apple apple apple	onion apple apple apple apple	apple apple apple apple apple	apple apple apple apple apple	apple apple apple apple apple	apple apple apple apple apple	apple apple apple apple apple	apple apple apple apple apple	apple apple apple apple apple	apple apple apple apple apple
IRISH POTATO	I. potato I. potato I. potato I. potato I. potato	onion onion dirt ??? ???	apple I. potato cabbage cabbage turnip	onion turnip I. potato onion I. potato	onion I. potato I. potato I. potato I. potato	S. potato I. potato cabbage I. potato S. potato	I. potato I. potato I. potato I. potato I. potato	I. potato I. potato ??? I. potato I. potato	I. potato I. potato I. potato I. potato I. potato	I. potato I. potato I. potato I. potato S. potato	I. potato S. potato I. potato S. potato S. potato	I. potato I. potato I. potato I. potato I. potato
SWEET POTATO	turnip? S. potato turnip turnip turnip	carrot carrot S. potato cabbage ???	turnip S. potato S. potato S. potato apple	apple carrot carrot carrot carrot	I. potato S. potato S. potato carrot S. potato	S. potato I. potato S. potato I. potato S. potato	turnip carrot carrot turnip S. potato	S. potato S. potato S. potato S. potato S. potato	S. potato carrot S. potato S. potato S. potato	turnip S. potato I. potato S. potato S. potato	turnip S. potato turnip turnip S. potato	cabbage I. potato S. potato I. potato S. potato

Stimulus / Subject	Response											
	W (Anosmic)	P	C	M	J	S	Cs	Me	G	Py	H	Sn
ONION	onion	onion	cabbage	turnip	turnip	onion	apple	onion	turnip	onion	onion	onion
	onion	onion	onion	onion	carrot	cabbage	turnip	onion	I. potato	onion	onion	onion
	onion	onion	onion	cabbage	turnip	cabbage	onion	onion	onion	apple	onion	onion
	onion	onion	apple	onion	onion	onion	onion	onion	onion	cabbage	onion	onion
	onion	onion	onion	onion	carrot	onion	apple	onion	onion	onion	apple	onion
CARROT	turnip	cabbage	turnip	carrot	turnip	turnip	carrot	S. potato	carrot	S. potato	cabbage	turnip
	turnip	I. potato	potato	cabbage	S. potato	carrot	S. potato	???	turnip	carrot	cabbage	carrot
	turnip	I. potato	cabbage	turnip	carrot	turnip	carrot	cabbage	carrot	S. potato	cabbage	carrot
	carrot	carrot	I. potato	I. potato	turnip	I. potato	carrot	carrot	cabbage	carrot	carrot	carrot
	cabbage	cabbage	turnip	turnip	turnip	turnip	carrot	cabbage	cabbage	turnip	cabbage	carrot
TURNIP	carrot?	???	I. potato	cabbage	onion	I. potato	I. potato	turnip	turnip	S. potato	turnip	apple
	carrot	cabbage	carrot	I. potato	onion	turnip	I. potato	S. potato	onion	turnip	turnip	turnip
	turnip	I. potato	I. potato	carrot	turnip	carrot	S. potato	cabbage	cabbage	turnip	carrot	turnip
	cabbage	I. potato	I. potato	turnip	turnip	cabbage	turnip	???	turnip	turnip	carrot	turnip
	I. potato	I. potato	I. potato	S. potato	cabbage	turnip	carrot	???	onion	carrot	turnip	turnip
SCORE	19	12	13	14	18	19	21	23	25	24	25	29

FEB 4 1922

PSYCHOLOGICAL REVIEW PUBLICATIONS OCTOBER, 1921

Journal of Experimental Psychology

EDITED BY

[illegible], 344 MADISON AVE., NEW YORK CITY
[illegible], PRINCETON UNIVERSITY (*Review*)
[illegible], YALE UNIVERSITY (*Monographs*)
[illegible] FRANZ, GOVT. HOSP. FOR INSANE (*Bulletin*) AND
MADISON BENTLEY, UNIVERSITY OF ILLINOIS (*Index*)

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[illegible] RAYMOND DODGE, WESLEYAN UNIVERSITY; KNIGHT
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[illegible]

CONTENTS

[illegible] of Prolonged and Concentrated Study in Memorizing:
EDWARD S. ROBINSON 327

[illegible] upon Phasic Adaptation:
LEONARD THOMPSON TROLAND 344

[illegible] F. L. WELLS, C. L. KELLEY and
GARDNER MURPHY, 391

PUBLISHED BIMONTHLY BY
[illegible]CAL REVIEW COMPANY
[illegible] ST., LANCASTER, PA., AND
[illegible], N. J.

[illegible], 1921, at the post-office at Lancaster, Pa.

Journal of
Experimental Psychology

VOL. IV, No. 5 OCTOBER, 1921

THE RELATIVE EFFICIENCIES OF DISTRIBUTED AND CONCENTRATED STUDY IN MEMORIZING

BY EDWARD S. ROBINSON

The University of Chicago

THE PROBLEM

It is a well-known fact, supported by the results of thirty or more researches,[1] that efficiency of learning is a function of the manner in which practice is distributed. The literature on this subject raises several more or less distinct questions: (1) What is the relative efficiency of concentrating all practice or study into one sitting as compared with dividing it into smaller units indulged in at varying intervals of time? (2) Granted that the total amount of practice is to be divided, what are the optimal units of practice? (3) What are the optimal intervals between given amounts of practice? The experiments to be reported in the present paper are concerned with the first of these questions and some of those factors which determine its answer for the memorizing of numbers.[2]

It has already been demonstrated that the relative efficiencies of concentrated and distributed study depend upon such factors as the nature of the material,[3] the length of the material,[4] and various features of the method of study.[5] In all

[1] See bibliography at end of paper.

[2] It is logically possible to fit the present experiments under the third as well as under the first of these questions. In fact, the results obtained throw some light also on the second question. This is due to the fact that these questions are all very closely related.

[3] Lyon, *J. Ed. Psychol.*, 1914, 5, pp. 1–9, 85–91, 155–163.

[4] Lyon, *op. cit.*

[5] See for example, Mould, Treadwell, and Washburn, *Amer. J. of Psychol.*, 1915, 26, pp. 286–288.

likelihood the relative efficiencies of concentration and distribution are somewhat influenced by many other factors, such as the degree of learning considered, methods of measuring efficiency (whether amount, accuracy or speed of recall is the criterion), the time which has elapsed since the final reading of the material, and the like. The effects of some of these factors are examined in the experiments which follow.

The Method

Two experiments were conducted. The memorized materials in both cases were lists of ten three-place numbers. The lists were made up by chance, except that:

1. In no number was 0 employed.
2. No digit within a number was immediately followed by a digit one more in value.
3. The same digit never occurred twice in the same number.
4. No digit in one number appeared in the immediately succeeding or following number.
5. The numbers 135, 357, 579, 246, and 468 were not employed.

In both experiments the numbers of any list were exposed for 2 seconds each with no appreciable interval between the covering of one number and the exposing of the succeeding number within a list. Between the immediately successive exposures or presentations of a complete list there was an interval of approximately 6 seconds.

In the first experiment each list of numbers was written on a long slip of paper which could be drawn through a double slit in a piece of white cardboard in such a way that only one number of the list came into view at a time. Timing was controlled with reference to a pendulum which swung on the wall behind the subject. In the second experiment the numbers were exposed by means of a hand-operated memory drum and timing was with reference to the clicks of a metronome.

Each experiment contained six conditions. In Experiment I., for example, a list of ten three-place numbers was

given either 12 presentations at a sitting, or 6 presentations at one sitting and 6 more presentations 24 hours later. Recall for each study method was measured at 5 minutes, 20 minutes, or 24 hours after the completion of study. The conditions of the two experiments are displayed in Table I.

TABLE I

EXPERIMENT I.

Condition A.—12 presentations of list of numbers, interval of 5 minutes, recall.
Condition B.—12 presentations of list of numbers, interval of 20 minutes, recall.
Condition C.—12 presentations of list of numbers, interval of 24 hours, recall.
Condition D.—6 presentations of list of numbers, interval of 24 hours, 6 more presentations of same list, interval of 5 minutes, recall.
Condition E.—6 presentations of list of numbers, interval of 24 hours, 6 more presentations of same list, interval of 20 minutes, recall.
Condition F.—6 presentations of list of numbers, interval of 24 hours, 6 more presentations of same list, interval of 24 hours, recall.

EXPERIMENT II.

Condition A.—6 presentations of list of numbers, interval of 5 minutes, recall.
Condition B.—6 presentations of list of numbers, interval of 20 minutes, recall.
Condition C.—6 presentations of list of numbers, interval of 24 hours, recall.
Condition D.—3 presentations of list of numbers, interval of 24 hours, 3 more presentations of same list, interval of 5 minutes, recall.
Condition E.—3 presentations of list of numbers, interval of 24 hours, 3 more presentations of same list, interval of 20 minutes, recall.
Condition F.—3 presentations of list of numbers, interval of 24 hours, 3 more presentations of same list, interval of 24 hours, recall.

The activity of the subjects between study and recall was uncontrolled, except for the fact that the subjects were asked to refrain from rehearsing the numbers during that interval.

Recall was written. The experimenter handed the subject a record book, open at a blank page, and said:

"I want you to write here in proper order as many as you can of the numbers you studied. Work as quickly and accurately as you can. Tell me as soon as you are through writing."

Since each subject was asked for a recall on 12 or 24 different occasions, the directions were dropped as soon as it was clear that the subject realized what was expected of him. I have found in previous work of this character that the constant repetition of such simple directions is either annoying

or highly amusing to the subject, and, for that reason, their omission probably introduces less error and inconstancy than their continuation.

The speed of recall was taken by means of a stop watch which was started as the blank page was placed before the subject and stopped when he indicated that he had reproduced as much of the material as he could.

Each subject employed was tested at least twice under all of the conditions of one experiment, and before he began the study of a new list of numbers he was always informed as to the nature of the condition before him.

Experiment I. employed 12 subjects and Experiment II. employed 6. The subjects in both cases were arranged into one or two groups of 6, and each subject in each group was put through the conditions in different order. The arrangement used is shown in Table II.

TABLE II.

ORDER IN WHICH DIFFERENT SUBJECTS WERE TESTED UNDER THE DIFFERENT EXPERIMENTAL CONDITIONS

Order	1st	2d	3d	4th	5th	6th
Subject 1	A	B	C	D	E	F
Subject 2	B	C	D	E	F	A
Subject 3	C	D	E	F	A	B
Subject 4	D	E	F	A	B	C
Subject 5	E	F	A	B	C	D
Subject 6	F	A	B	C	D	E

Each of the two groups of subjects in Experiment I. went through two cycles as represented in Table II. The one group in Experiment II. went through four cycles. This gave a total of 24 separate tests for every experimental condition.

Obviously the arrangement of conditions adopted was an attempt at least partially to equate the amounts of previous practice effective for the different conditions. A further precaution was taken in that the subjects were given three practice sittings where lists of ten three-place numbers were studied and recalled. It also was so arranged that each list of numbers used was studied by some subject under each of the

experimental conditions. This should have compensated in some degree for possible inequalities in the difficulties of the lists.

At no sitting did a subject work with more than one list of numbers. A subject was never asked, for instance, to begin memorizing a new list of numbers at a sitting during which he had previously studied or recalled another list. It was my intention here to guard as carefully as possible against positive or negative transfer between the lists. Of course, where a subject works day after day with units of similar material there must be considerable transfer of which it is practically impossible to take account. It seems reasonable to suppose, however, that the amount of transfer between the different units of material will be greatly reduced if not more than one unit is dealt with at a sitting.

Not all of my subjects were tested at the same time of day. Such an arrangement might have been desirable, but it was hardly practicable. Nevertheless, each subject had a regular sitting time, and this was kept constant with the exception of a few variations of not over two or three hours.

The subjects in Experiment I. were undergraduate and graduate students in Yale University, none of whom had had extended experience of this sort. Five graduate students and one undergraduate in the University of Chicago served as subjects in Experiment II.

A number of Yale University students in the writer's class in experimental psychology acted as experimenters in Experiment I. Their work was carried out under detailed instructions and I have no reason to feel anything but confidence in its accuracy. The writer was the only experimenter in Experiment II.

The criteria of recall were three: (1) Total Digits—the number of digits recalled irrespective of their correctness; (2) Correct Digits—the number of digits recalled which were correct in both content and position (where a three-place number was removed by not more than one place from its correct position a penalty for one incorrect digit was applied); (3) Time—the total time taken for recall divided by the total number of digits recalled.

Results

Table III. presents the average performances under the conditions of Experiment I. Columns bearing the title *6 + 6* contain the average performances where the memorized material was given 6 presentations at one sitting and 6 presentations 24 hours later. The columns headed *12* contain the average performances where the memorized material was given all 12 presentations at one sitting. Table IV. presents the averages under the conditions of Experiment II. The notation is analogous to that of Table III. With two exceptions each average in these tables represents 24 individual measurements. One of these exceptions represents 22 measurements and the other 23.

Table III

Experiment I. (Means of All Individuals and Both Cycles)

	Recall after 5 Minutes		Recall after 20 Minutes		Recall after 24 Hours	
	6 + 6	*12*	*6 + 6*	*12*	*6 + 6*	*12*
Total digits	25.4	24.6	24.8	25.0	21.6	20.3
Correct digits	23.1	20.8	21.3	20.2	15.4	9.6
Time per digit (seconds)	1.85	2.55	2.15	2.25	2.8	3.4

Table IV

Experiment II. (Means of All Individuals and All Cycles)

	Recall after 5 Minutes		Recall after 20 Minutes		Recall after 24 Hours	
	3 + 3	*6*	*3 + 3*	*6*	*3 + 3*	*6*
Total digits	19.3	20.4	19.1	19.7	14.5	14.0
Correct digits	14.6	16.9	13.8	14.6	8.8	6.8
Time per digit (seconds)	2.6	2.2	2.2	2.8	3.92	3.95

According to eight out of the nine pairs of values in Table III. the distributed form of study is superior to the more concentrated form. There is little evidence in these unevaluated averages concerning the effects which the progress of forgetting or the criterion of measurement employed may have upon this superiority.

The averages from Experiment II. (Table IV.) show no such clear advantage for the distributed study. In fact, five

out of nine pairs favor concentrated study. Evidently the effects of dividing a series of presentations into halves 24 hours apart are dependent upon the total number of presentations employed. The dividing into halves of 12 presentations is advantageous; the dividing into halves of 6 presentations is, if anything, disadvantageous.

While, in Experiment I., so far as mere averages are concerned, there seems to be no significant change in the relative results of the two methods of study with the progress of forgetting, the averages from Experiment II. tell a different story. At 5 minutes and 20 minutes after the final presentation, the concentrated method shows the greater efficiency, but at the end of 24 hours this condition is reversed and all three[1] criteria favor distribution.

TABLE V

RESULTS OF EXPERIMENT I.—RECALL AFTER 5 MINUTES

First Cycle

Subjects	Total Digits		Correct Digits		Time per Digit (Seconds)	
	6 + 6	12	6 + 6	12	6 + 6	12
1	30	24	26	21	1.4	1.0
2	15	18	15	18	3.0	1.9
3	30	30	28	22	1.8	2.7
4	30	30	28	19	1.5	2.8
5	30	27	27	23	1.4	2.5
6	18	9	17	7	2.0	3.9
7	23	16	16	10	1.5	3.7
8	30	30	26	26	3.3	5.0
9	30	30	30	30	1.0	1.0
10	27	21	25	9	1.8	2.8
11	18	9	13	7	1.4	5.5
12	24	30	18	20	2.5	2.0
Mean	25.4	22.8	22.4	17.7	1.9	2.9

No attempt has been made to evaluate the means in Tables III. and IV. by the use of the conventional methods of calculating P.E.$_m$ or S.E.$_m$. It is quite evident that the assumptions underlying these methods render them inapplicable to the data of these experiments. Table V., VI., and

[1] In the case of *time of recall* there is probably no significant difference between the two methods.

Second Cycle

1	20	24	17	22	2.7	1.0
2	15	21	15	21	1.2	1.7
3	30	30	29	25	2.3	2.0
4	30	30	30	24	1.6	2.3
5	30	27	30	23	0.7	2.5
6	15	12	12	10	2.3	3.7
7	19	24	17	24	1.8	1.4
8	30	30	27	28	2.3	1.3
9	30	30	30	30	0.7	2.7
10	30	30	30	26	2.0	2.7
11	26	28	25	26	1.5	1.9
12	30	30	24	27	2.0	3.5
Mean	25.4	26.3	23.8	23.8	1.8	2.2
No. times superior	8	6	13	8	16	7
No. ties	10		3		1	

Total no. times $6 + 6$ is superior = *37*
Total no. times *12* is superior = *21*
Total no. ties = *14*

TABLE VI

RESULTS OF EXPERIMENT I.—RECALL AFTER 20 MINUTES

First Cycle

Subjects	Total Digits		Correct Digits		Time per Digit (Seconds)	
	6 + 6	*12*	*6 + 6*	*12*	*6 + 6*	*12*
1	15	30	13	15	2.6	1.1
2	15	15	15	13	1.3	2.2
3	30	30	26	26	1.5	2.2
4	30	30	30	16	2.3	3.1
5	30	30	22	25	1.4	1.7
6	12	18	6	9	1.5	2.2
7	19	24	14	19	3.1	1.9
8	27	27	21	17	3.3	4.1
9	30	30	30	30	1.8	1.3
10	30	24	26	16	1.3	1.2
11	18	16	15	10	1.6	1.9
12	27	30	17	24	1.5	4.0
Mean	23.6	25.3	19.6	18.3	1.9	2.2

VII., Experiment I., and Tables VIII., IX., and X., however, include the detailed results of those of Experiment II. An examination of these tables will throw light upon the validity of the generalizations made upon more general bases and, perhaps, reveal some important facts not apparent in Tables III. and IV.

Each table contains 72 pairs of values, the members of which can be compared in estimating the relative efficiencies of the two methods of study. Pooling all of the comparisons for Experiment I., Tables V., VI., and VII., it appears that:

Distributed study is superior 114 times
Concentrated study is superior 63 times
Neither is superior 39 times

Second Cycle

1	30	24	28	23	1.0	1.6
2	15	18	15	16	6.6	1.9
3	30	30	27	22	2.5	2.4
4	30	30	30	26	1.6	2.5
5	30	30	30	25	0.8	1.7
6	15	18	15	16	2.0	2.3
7	25	12	21	10	1.2	2.2
8	30	16	21	14	2.3	5.0
9	30	30	30	30	1.8	1.1
10	27	30	19	26	3.7	1.3
11	19	28	16	27	2.3	0.9
12	30	30	24	29	3.0	4.7
Mean	25.9	24.7	23.0	22.0	2.4	2.3
No. times superior	5	8	11	10	15	9
No. ties	11		3		0	

Total no. times $6 + 6$ is superior = *31*
Total no. times *12* is superior = *27*
Total no. ties = *14*

TABLE VII

RESULTS OF EXPERIMENT I.—RECALL AFTER 24 HOURS

First Cycle

Subjects	Total Digits		Correct Digits		Time per Digit (Seconds)	
	$6 + 6$	12	$6 + 6$	12	$6 + 6$	12
1	15	24	9	9	2.0	1.6
2	15	15	6	7	6.9	9.0
3	30	30	18	14	1.8	2.8
4	30	30	30	14	2.8	3.3
5	30	30	17	15	1.7	3.3
6	12	9	6	3	2.5	0.8
7	13	9	10	7	1.5	3.9
8	20	24	13	4	5.0	2.5
9	27	27	23	15	1.1	2.2
10	24	19	15	10	1.5	5.0
11	12	9	10	5	2.0	2.2
12	28	27	18	8	5.0	11.0
Mean	21.3	21.1	14.6	9.2	2.8	4.0

Second Cycle

1	27	21	22	15	1.5	2.4
2	15	4	13	3	6.3	7.5
3	30	30	21	16	2.6	2.5
4	30	30	21	13	1.8	3.5
5	30	30	23	17	2.0	3.3
6	12	6	8	6	2.5	2.5
7	9	3	7	2	1.5	1.7
8	18	24	4	7	1.7	2.5
9	30	21	25	2	2.1	1.4
10	27	30	20	27	3.7	1.3
11	12	8	11	6	2.5	2.5
12	24	27	18	6	5.0	3.0
Mean	22.0	19.5	16.1	10.0	2.8	2.8
No. times superior	11	5	20	3	15	7
No. ties	8		1		2	

Total no. times $6 + 6$ is superior $= 46$
Total no. times 12 is superior $= 15$
Total no. ties $= 11$

TABLE VIII

RESULTS OF EXPERIMENT II.—RECALL AFTER 5 MINUTES

First Cycle

Subjects	Total Digits		Correct Digits		Time per Digit (Seconds)	
	$3 + 3$	6	$3 + 3$	6	$3 + 3$	6
1	21	23	18	20	1.4	2.0
2	21	27	15	23	2.6	2.0
3	15	18	3	14	1.4	1.7
4	30	24	29	16	1.3	3.7
5	6	10	4	10	7.5	2.5
6	12	12	6	9	3.4	2.7
Mean	17.5	19.0	12.5	15.3	2.9	2.4

Second Cycle

1	24	29	18	26	2.2	2.1
2	27	30	18	30	2.0	0.9
3	21	15	14	9	1.5	2.4
4	28	30	23	30	1.8	1.0
5	6	9	3	6	5.0	2.8
6	12	15	12	12	1.7	2.9
Mean	19.7	21.3	14.7	18.8	2.4	2.0

Third Cycle

1	20	30	17	28	2.4	1.6
2	25	30	18	30	1.7	1.0
3	18	15	7	9	1.2	1.7
4	30	30	28	25	2.6	1.3
5	9	12	9	4	2.8	2.2
6	12	15	11	13	2.2	2.7
Mean	19.0	22.0	15.0	18.2	2.2	1.8

Fourth Cycle

1	30	25	25	22	1.6	2.0
2	27	30	24	20	1.6	2.2
3	21	12	14	7	0.8	0.6
4	30	30	27	30	2.3	1.1
5	6	6	3	5	7.7	6.1
6	12	12	3	7	3.2	2.9
Mean	21.0	19.2	16.0	15.2	2.9	2.5
No. times superior	5	14	7	16	9	15
No. ties	5		1		0	

Total no. times $3 + 3$ is superior $= 21$
Total no. times 6 is superior $= 45$
Total no. ties $= 6$

TABLE IX

RESULTS OF EXPERIMENT II.—RECALL AFTER 20 MINUTES

First Cycle

Subjects	Total Digits		Correct Digits		Time per Digit (Seconds)	
	$3 + 3$	6	$3 + 3$	6	$3 + 3$	6
1	24	19	20	9	1.4	2.2
2	27	28	18	26	3.1	2.0
3	21	18	7	15	1.3	1.0
4	30	30	25	19	1.6	2.6
5	9	9	9	3	3.0	2.8
6	9	9	1	5	2.6	2.7
Mean	20.0	18.8	13.3	12.8	2.2	2.2

Second Cycle

1	20	25	17	21	1.9	3.4
2	25	30	22	23	1.4	1.5
3	18	24	6	22	1.5	1.3
4	30	30	30	28	1.3	2.0
5	9	9	4	4	1.9	2.7
6	9	15	4	7	2.1	2.7
Mean	18.5	22.2	13.8	17.5	1.7	2.3

Third Cycle

1	24	19	18	6	2.0	2.5
2	27	27	13	25	1.7	2.3
3	21	21	8	10	1.5	1.9
4	27	30	27	26	2.4	2.8
5	9	9	6	0	2.7	7.3
6	9	13	4	9	2.9	5.0
Mean	19.5	19.8	12.7	12.7	2.2	3.6

Fourth Cycle

1	21	24	19	15	3.0	2.2
2	24	27	21	27	2.0	1.4
3	21	18	13	15	1.7	0.9
4	27	27	24	27	3.0	3.1
5	9	6	6	4	3.9	5.2
6	9	6	9	4	2.5	6.3
Mean	18.5	18.0	15.3	15.3	2.7	3.2
No. times superior	6	9	10	13	17	7
No. ties	9		1		0	

Total no. times $3 + 3$ is superior = *33*
Total no. times *6* is superior = *29*
Total no. ties = *10*

TABLE X

RESULTS OF EXPERIMENT II.—RECALL AFTER 24 HOURS

First Cycle

Subjects	Total Digits		Correct Digits		Time per Digit (Seconds)	
	3 + 3	*6*	*3 + 3*	*6*	*3 + 3*	*6*
1	12	9	5	8	4.4	4.4
2	21	21	14	15	2.6	1.5
3	9	21	6	8	2.2	1.7
4	30	21	30	6	3.2	8.1
5	6	0	3	0	3.3	—[1]
6	9	9	7	1	2.2	1.8
Mean	14.5	13.5	10.8	6.3	3.0	3.5

Second Cycle

1	13	9	6	0	3.5	7.3
2	15	16	11	1	2.8	4.1
3	18	12	8	12	1.2	0.8
4	27	27	25	25	4.1	3.1
5	3	6	1	0	6.0	6.5
6	15	9	4	1	3.1	2.9
Mean	15.2	13.2	9.2	6.5	3.4	4.1

Third Cycle

1	17	25	8	5	3.2	3.5
2	18	18	9	0	2.7	3.7
3	18	21	9	8	1.4	1.2
4	24	27	7	23	5.1	3.1
5	3	0	2	0	21.0	—[1]
6	12	6	3	1	2.9	4.0
Mean	15.3	16.2	6.3	6.2	6.0	3.1

Fourth Cycle

1	11	12	5	8	3.2	3.7
2	15	12	6	8	3.9	4.8
3	21	18	14	12	1.5	1.6
4	22	24	20	15	4.8	5.8
5	0	3	0	2	—[1]	12.3
6	9	9	7	5	3.0	2.3
Mean	13.0	13.0	8.7	8.3	3.3	5.1
No. times superior	10	9	15	8	11	9
No. ties	5		1		1	

Total no. times $3 + 3$ is superior = *36*
Total no. times *6* is superior = *26*
Total no. ties = *7*

From a similar pooling of all the comparisons of Experiment II., Tables VIII., IX., and X., it appears that:

Distributed study is superior 90 times
Concentrated study is superior 100 times
Neither is superior 23 times

These results strikingly support the generalization that the division of 12 presentations into halves 24 hours apart is highly advantageous, while a similar division of 6 presentations probably has a deleterious effect. Of course, a possibility remains that at least some part of this difference is due to the fact that different subjects were used under the two sets of conditions. Aside from this consideration, however, there are a number of factors which may operate to make distributed study relatively more advantageous in Experiment I. than in Experiment II.:

1. It is quite possible that the optimal time for putting an end to the first study of ten three-place numbers is after something more than 3 presentations;

2. Perhaps 3 presentations are fewer than are contained in optimal study periods for this material; and it is possible that:

[1] Subject no. 5 has no time values at these points because of inability to recall any digits.

3. If an interval of something less than 24 hours had elapsed between the first and last 3 presentations, the division of 6 presentations into halves would have been as advantageous as a similar division of 12 presentations.

Comparing the results of the two methods of study at different stages in the process of forgetting, it is evident that in Experiment I., Tables V., VI., and VII., the superiority of the distributed method of study is greater after 24 hours than it is after 5 minutes or 20 minutes. In the latter cases it is favored in 37 and 31 comparisons out of 72, and in the former case in 46 comparisons. This fact appears more plainly in these detailed data than in the averages of Table III.

The examination of Tables VIII., IX., and X., Experiment II., reveals facts in essential agreement with those of Experiment I. After 5 minutes, distributed study is favored in only 21 out of 72 comparisons, after 20 minutes it is favored by 33 comparisons and after 24 hours by 36. According to both of these experiments, then, the relative efficiencies of the two methods of study are functions of the time elapsing since the final presentations.

Again pooling the data of Tables V., VI., and VII., certain facts appear regarding the effects of utilizing different scoring methods:

According to the total number of digits recalled,

Distributed study is superior	*24 times*
Concentrated study is superior	*19 times*
Neither is superior	*29 times*

According to the number of digits recalled correctly,

Distributed study is superior	*44 times*
Concentrated study is superior	*21 times*
Neither is superior	*7 times*

According to the average number of seconds required to recall each digit,

Distributed study is superior	*46 times*
Concentrated study is superior	*23 times*
Neither is superior	*3 times*

Similarly, pooling the data of Tables VIII., IX., and X., it appears that, in Experiment II.:
According to the total number of digits recalled,

Distributed study is superior	*21 times*
Concentrated study is superior	*32 times*
Neither is superior	*19 times*

According to the number of digits recalled correctly,

Distributed study is superior	*32 times*
Concentrated study is superior	*37 times*
Neither is superior	*3 times*

According to the average number of seconds required to recall each digit,

Distributed study is superior	*37 times*
Concentrated study is superior	*31 times*
Neither is superior	*1 time*

Both experiments agree in indicating that *correct digits recalled* and *time of recall* show a greater advantage for distributed study than does *amount of recall*.[1]

The results of this investigation, then, suggest that the relative merits of distributed and concentrated study of numerical material depend upon: (1) the total amount of study considered, (2) the units into which that material is divided, (3) the stage in the forgetting process at which memorial efficiency is tested, and (4) the criterion of efficiency employed; *e.g.*, amount, accuracy, or time of recall.

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[1] There are many more perfect scores according to *amount of recall* than according to either of the other criteria—of course, a perfect time score would be as difficult to obtain as to define. Because of this fact there are more ties according to the amount criterion, and this naturally decreases its efficiency as a differentiating agency.

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THE COLORS PRODUCED BY EQUILIBRIUM PHOTOPIC ADAPTATION

BY LEONARD THOMPSON TROLAND,

Harvard University, Emerson Hall

I. Introduction

In a recent paper Sheppard reports extensive and seemingly careful experiments which tend to support Hering's belief—a necessary deduction from his visual theory—that equilibrium adaptation of the retina to any stimulus yields a sensory quality of neutral mid-gray. Sheppard[1] finds that with practically all types of stimuli, whether high or low in intensity and whether or not of spectral purity, the final result of continued fixation is a gray. Sheppard's results seem to be in definite disagreement with the general outcome of quite an elaborate series of experiments which the writer made in 1914-15 at the Harvard Psychological Laboratory and which have not hitherto been described in detail. The experiments led to the conclusion that prolonged stimulation of the retinal cones with stimuli which initially evoke colors of considerable saturation does not in general bring about reduction of the sensation to a gray. In certain instances, the conditions of which can be quite definitely specified, such a reduction does occur, but the general rule was in sharp conflict with the implications of the Hering theory.

The experiments were reported verbally in summary at the meeting of the Experimental Psychologists at Harvard in 1917, and it is possible that Sheppard's work may have some indirect reference to the views which were advocated at that time. The results have also been mentioned in a general paper on "Apparent Brightness,'[2] incidentally in a paper on

[1] Sheppard, H., 'Foveal Adaptation to Color,' *Am. Journ. of Psychol.*, 1920, 31, 34-58.

[2] Troland, L. T., 'Apparent Brightness: Its Conditions and Properties,' *Trans. of the Illum. Eng. Soc.*, 1916, 11, 949-966.

special after-image phenomena,[1] and were utilized in 1914 to substantiate a general mathematical theory of adaptation[2] which was based on assumptions contrary to those of Hering. Since the question which is at issue is of great importance in determining the value of Hering's general conceptions for visual theory, as well as in relation to any supposed mechanism of visual excitation, it seems desirable that the results be reported in full. The writer believes that the discrepancy between his observations and those made by Sheppard and other supporters of the Hering theory will be found in some difference between the conditions under which the experiments were made, the principal factor being in all probability the control of the pupil. The majority of Sheppard's observations were made with the natural pupil, and those in which he employed an artificial pupil apparently did not involve any accurate control of the registration of the artificial pupil with the natural pupil. In all of the observations reported in this paper, on the other hand, or at least in those upon which reliance is placed for the refutation of the Hering theory, an artificial pupil was employed and care was taken to secure satisfactory register between the natural and artificial pupils. It is worthy of note that in Sheppard's series with spectral stimuli[3] in which an artificial pupil was employed he found it impossible to obtain 'complete adaptation' at high intensities.

The spontaneous fluctuations to which the natural pupil is almost always subject, produce variations in the illumination of the retina, and such variations result in very powerful after-image effects which are capable of quite submerging the normal course of the adaptation process. Only by carefully eliminating such fluctuations, and their accompanying changes in retinal illumination, can we hope to study the adaptation process in its purity. One of the most interesting features of the writer's work on foveal adaptation, only a portion of which will be reported in the present article, lay

[1] Troland, L. T., 'Preliminary Note: The Influence of Changes of Illumination upon After-Images,' *Amer. J. of Psychol.*, 1917, 28, 497–503.

[2] Troland, L. T., 'Adaptation and the Chemical Theory of Sensory Response,' *Amer. J. of Psychol.*, 1914, 25, 500–527.

[3] *Loc. cit.*, p. 55.

in the quantitative study of these secondary after-image phenomena which appear with changes in the retinal illumination. The phenomena in question may consist either in a marked augmentation of the effect which goes with stationary illumination or, on the other hand, they may constitute a reversal of the later effect. The first type of change goes, in general, with diminution of the retinal illumination, caused by contraction of the pupil or otherwise, while the second species of influence accompanies the reverse change. It is true that in general these illumination-change phenomena are short lived; but they are of sufficient duration to cause an observer to make a judgment of the consummation of complete adaptation and thus bring a given observation to a close.

Some of the general principles which determine one of these effects have already been discussed briefly in another paper, and further details will be considered in the present and later articles.

II. The Quality of the Equilibrium Sensation

The majority of theories of visual response assume that the intensity of any given component of the visual sensation is a function of the velocity of a corresponding chemical change. With the possible exception of the sensation of black, this function is such that when the velocity in question is zero the intensity of the corresponding sensory *quale*[1] is also zero, and also such that an increase or decrease in the velocity is characteristically accompanied by an increase or decrease, respectively, in the intensity. Since it is customary to represent chemical velocities as rates of change in the concentration of the reacting substance, or substances, we may state that if the visual intensity considered is v, while the concentration of the substance is s, and t the time, these theories require in general that:

$$(1) \qquad v = f^d(\pm\, ds/dt),$$

where $f^d(\ )$ is a function having the properties specified above.

The above general premise of all chemical theories of vision has obvious, important consequences, on account of

[1] By "the intensity of a sensory quale" is meant the measure of any attribute, *e.g.*, the degree of redness or of brightness.

the inevitable law that the velocity of a chemical change decreases or increases with a corresponding alteration in the concentration of the active substances, and such a change in concentration is the very thing called for by the rate of change itself. In general, then, without undue exactness of expression:

(2) $$ds/dt = -f^d(s)$$

and

(3) $$s = \int (ds/dt)dt,$$

that is, other things equal, the velocity is greater the greater the concentration of the reacting substance,[1] and the concentration is greater the longer the time during which the change has been occurring and the higher the velocity during that time. If we limit ourselves to a so-called irreversible monomolecular reaction, equation (2) becomes a proportionality, so that

(4) $$ds/dt = -ks,$$

where k is a constant. This equation states that the rate at which the substance, S, is being destroyed is at every instant proportional to its concentration. A simple integration of (4) gives us the relationship:

(5) $$\log s = -kt, \quad \text{or} \quad s = e^{-kt},$$

where e is the base of the natural system of logarithms. From (4),

(6) $$ds/dt = -ke^{-kt},$$

which asserts that the rate of decomposition of S becomes less as time goes on, approaching zero 'asymptotically.' But, from (1) it follows that

(7) $$v = f^d(\mp ke^{-kt}),$$

which states that with time the sensation *quale*, V, becomes less and less intense, and after a sufficiently long period will be reduced below the threshold and hence, psychologically, to

[1] The minus sign in equation (2) is due to the convention of taking the rate of change as negative when it is destructive of the substance, S.

zero. This process obviously corresponds to what is usually called visual or retinal 'fatigue,' and in a general way the actually observed changes in v with time follow a curve similar to that demanded by the above equation (7).

However it is one of the principal points of the experimental work which is to be described below to show that, at least in one respect, equation (7) is not generally valid, *viz.*, that it is not an essential characteristic of visual response that continued activity should result in ultimate complete exhaustion. Now all chemical theories of vision provide a mechanism of 'repair' whereby the change in the concentration of the sensitive substance which occurs during sensation can be compensated. If the original change was destructive or 'katabolic,' the repair is of course constructive, or 'anabolic,' and the latter change always implies a velocity term opposite in sign to that of the former. It is generally assumed that the repair goes on during stimulation as well as thereafter, and if this is the case it is obvious that the concentration of the sensitive substance will never be reduced to zero, no matter how long the excitation continues. If we suppose the repair process to have a velocity r at any time the intensity of the visual *quale* at that time will be

$$v = f^d(\mp ke^{-kt} \pm r), \tag{8}$$

so that after a very long time:

$$v = f^d(\pm r). \tag{9}$$

If r is a constant or becomes so after the 'long' period of time, equation (9) represents a steady state of sensation which will continue indefinitely. Such a condition, in general, we shall call one of *sensory equilibrium.*

It is characteristic of the visual theory of Hering[1] that certain visual qualities are attributed not only to the katabolic but also to the anabolic phase of the metabolism, so that the stimulation process of one sensation is the repair process of another sensation, which is defined as its 'antagonist.'

[1] Hering, E., 'Zur Lehre vom Lichtsinne,' *Sitzb. d. Wien. Akad.*, 1872–1874. *2 Aufl.*, 1878, p. 70.

Moreover, except in the case of the 'black-white substance,' when the opposed velocities are arithmetically equal these paired qualities completely inhibit each other, so that the theory in question implies a complete absence of both of these antagonistic qualities under conditions of sensory equilibrium.[1] As is well known, the qualities thus opposed are red to green, and yellow to blue. It is a recognized inconsistency of Hering's theory that black and white, although given the same psycho-physical basis as the other visual qualities, do not antagonize, but instead fuse with each other.

In harmony with Hering's point of view and what is in all probability a correct psychological analysis, we shall consider any visual sensation as resolvable into a limited number of component intensities, *viz.*, different *degrees* of black, white, red, yellow, green and blue. For these qualities we shall employ the abbreviations: N (noir), W, R, Y, G, and B, respectively. For the corresponding degrees we may employ the lower case letters: n, w, r, y, g, and b. Everyday experience teaches that, ordinarily at least, R and G are mutually exclusive, as are also Y and B; but that with this restriction a visual sensation may exhibit any combination of the variables named, with a wide range of relative intensities.

Let us define as an *equilibrium sensation* any sensation which accompanies a process in the visual system which involves no concomitant alteration in the sensitivity of the latter. Such a sensation will remain when the process of fatigue or adaptation has reached its asymptotic limit.

Now, as we have stated, it is a consequence of Hering's theory that there is only one possible constitution for such a sensation, *viz.*, $N+W$, in which $w=n$, a mixture denominated 'mid-gray.' According to this view, it can make no difference whether the equilibrium sensation is determined by an external or an internal stimulus, or whether the original sensation was chromatic or achromatic. All sensory processes, if permitted to go on undisturbed, must finally meet a common fate.

The most obvious method for an attempt to refute this consequence of Hering's theory would seem to be to fixate

[1] Hering, E., 'Grundzüge der Lehre vom Lichtsinn,' 1905–1911.

different stimulus fields during long periods, and to observe whether a time can be reached when all of the differentiæ resolve themselves into a mid-gray. In the present paper a report is made of the results of experiments of this character, the stimuli employed covering a fairly wide range of conditions. The abolition of all visual differences during a period of fixation amounts to a 'disappearance' of the stimulus, and it is a fact so well established that it must be accepted at the outset that such disappearances often occur. Hence one of the problems to be considered is that of the exact circumstances which make such lapses possible, and whether they argue for Hering's view. This is a field of investigation in which already a great deal of work has been done, but in which, nevertheless, the writer believes he has found certain new facts. The final outcome of the paper will be a denial that the equilibrium sensation is a neutral mid-gray, except in certain very special cases, and the phenomena of stimulus disappearance will be given explanations which do not imply this proposition.

III. The Equilibrium Sensation with Large Uniform Stimulus Fields

The simplest case in which to attack the problem of the quality of equilibrium sensations would seem to be that of the complete exclusion of light from the normally conditioned eye. This cannot be called an absence of stimulation, since, especially in such a view as Hering's, it is proper to consider darkness as a definite visual stimulus. But if Hering's doctrines are correct, darkness, like all other environmental conditions, is a stimulus only when it is a change. Black results from the cutting off of light, but the continued absence of light is accompanied by a lapse of the black sensation into a neutral mid-gray. The question therefore presents itself for empirical consideration as to whether the sensation yielded by the completely rested retina in the dark is actually neutral mid-gray. Hering himself considers this point at some length[1] and admits that the visual quality which one experi-

[1] 'Zur Lehre vom Lichtsinne,' p. 89.

ences upon awakening in the morning in a closely shuttered room suggests black more than it does white, and hence might be thought not to be such a gray. Hering explains this appearance by saying that although we have had experience of practically perfect whites, we have never had one of absolute black and that, consequently, our conception of mid-gray is weighted in the direction of white. This makes a true mid-gray seem too dark.

The author's observations confirm the naïve impression that the rest idio-retinal sensation is a great deal blacker than an unsophisticated mid-gray, but his reasoning does not wholly substantiate Hering's attempted reconciliation of such observations with his theory. In the first place, it is doubtful whether we can come any closer to an experience of pure white than we can to one of pure black. What reason have we for believing that 'pitch dark' lies farther from utter blackness than 'dazzling white' does from a catholic whiteness? Hering's argument, to say the least, presupposes his own theory. If, as such hypotheses as those of Helmholtz would imply, black is a result of the absence of retinal excitation, it would seem easier to produce a pure black than a pure white, since, theoretically, the white process could increase indefinitely in intensity whereas the black process would find its natural limit with complete retinal fatigue, a conceivably attainable state of affairs. In accordance with Hering's hypothesis, on the other hand, no natural limit can exist for either *n* or *w*. Consequently it would appear necessary to estimate both blackness and whiteness on the basis of mid-gray as a standard, rather than *vice versa*. If this is what we actually do the empirical evidence would seem to be against Hering's doctrine of the median quality of the equilibrium sensation in the absence of external stimulus forces.

As will be emphasized more strongly later on, it is probable that there is a central process in vision—closely allied with the functions of perception and discrimination—which causes us to become 'mentally blind' to sensory qualities which are uniformly distributed in both space and time. This process is slow-acting, but it obeys a law similar to that governing Hering's equilibrium sensation: it makes it impossible for an

observer to 'tell' whether or not the monotonous quality is present, and hence favors judgments of neutrality with regard to all sensations which have persisted for a long time unchanged. If such a process is active in the limitation of perception and introspection, we should expect the idioretinal rest sensation to be judged as mid-gray rather than as black or dark gray. Thus, if central adaptation fails to take effect, surely there must be some adequate peripheral cause, such as marked and permanent depression of the retinal activity below that characteristic of mid-gray.

Suppose, now that in place of darkness we fill the eye with a bright white light, and continue such stimulation indefinitely. If Hering's theory is correct, no matter how brilliant the light the final sensation will be that of neutral mid-gray.

Experiment I. The Equilibrium Sensation for Direct Sunlight on White Paper

As a preliminary test of this point the following experiments were tried. A large sheet of white drawing paper directly illuminated by the early afternoon sun on a cloudless day was viewed at such a distance as to yield a uniform stimulation field of 60 horizontal and 50 vertical degrees. Fixation of this field, which had a brightness — calculated from direct flicker photometric measurements—of about 346,600 candles per square meter, was steadily continued for ten minutes, in each trial, with the following results.

At the outset the stimulus appeared dazzlingly bright, and during the first thirty seconds or so it showed a very rapid decrease in apparent luminosity, so that at the end of about one minute it seemed as if illuminated by, roughly, one twentieth of the actual light intensity. Whatever significance may be assigned to an estimate of this sort, it is certain that the gray sensation to which it refers was very much brighter in each case than a naïvely conceived mid-gray. Moreover after the first minute no further darkening could be observed, and during the ensuing nine minutes whatever alteration did occur was in the direction of a restoration of the original brightness rather than that of its continued decrease. This experiment was repeated a number of times on different days

with the same results. It would appear from the above observations that (1) prolonged exposure of the retina to large, very intense, achromatic stimuli does not involve a reduction of the sensation to neutral mid-gray, but rather to a *bluish* gray the luminosity of which depends upon that of the stimulus and is much greater than that of mid-gray; and (2) that the reduction in luminosity which does take place occurs very rapidly so that the sensation soon comes to a permanent equilibrium state characterized by the just mentioned quality.

Experiment II. The Equilibrium Sensation for Direct Sunlight on Large Colored Papers

The principle of the reduction of visual sensation, by adaptation, to neutral mid-gray applies in Hering's theory not only to black and white but to all of the color qualities as well. As already stated, this is a consequence of his doctrine of mutually antagonistic color pairs. To put the question to an empirical test, large sheets of colored paper (of the Hering and Milton Bradley series) were fixated in direct sunlight under conditions exactly similar to those obtaining for the white stimulus just considered. Table I. summarizes the results of these experiments.

It will be seen by reference to the table that only in the case of yellow and green was there total disappearance of the color quality which was characteristic of the primary field and, even here, the disappearance was not permanent. In all cases there was, of course, a marked decrease in saturation and brightness, and sometimes a change in the exact hue-constitution of the field, very soon after the exposure was commenced. This change did not continue, however, and the quality of the area quickly settled down to an equilibrium condition which—apart from some tendency to revert to the original hue—was steadily maintained thereafter. It should be noted that those cases in which the primary hue showed phases of complete disappearance, were with stimuli of very high intensity, both the Milton Bradley yellow and Hering green being papers of high reflecting power.

TABLE I

THE FATIGUE CHANGES IN SENSATION WITH LARGE CHROMATIC STIMULI OF HIGH INTENSITY

General Conditions: Size of stimulus fields: approximately 60° horizontally by 50° vertically; Time of each fixation period: 10 minutes. Colored papers from the Hering (Rothe) and Milton Bradley series were employed. These were viewed in direct sunlight on cloudless March and April days, between 1 and 3 P.M. Subject: *T.* Monocular fixation.

Explanation of Tables: In the first column, below, are symbols for the normal quality of the stimulus, together with the abbreviations, Her. and M-B. to indicate whether the papers used belong to the Hering or to the Milton Bradley series, respectively. The second column given the calculated (approximate) value in candles per square meter of the brightness of each of the paper surfaces, the data for these calculations being obtained by flicker photometry of the papers actually employed. The next three columns contain descriptions of the quality of the sensation during three successive periods of the fixation, the first being that introduced by the rapid initial change, the third the final minute, and the second an intermediate phase.

Stimulus	Intensity	Color Phases			Remarks
		Initial	Intermed.	Final	
NR M-B.....	38,500	*r*	*r*	*r*	
R Her.....	50,000	*wr'*	*wr*	*w'r*	Clear revival of the red
YR Her.....	88,500	*wbg*	*yg*	*wry*	
Y M-B.....	215,000	*w*	*wgy*	*wgy*	Yellow very faint
Y Her.....	130,000	*gy*	*g'y*	*g'y*	
G Her.....	80,500	*wg'b'*	*wgb*	*wgb*	Moments of gray
GY M-B.....	117,500	*b'w*	*b''g''w*	*b''g''w*	Green very faint
BG Her.....	31,000	*b'w*	*b'w*	*b'w*	
B M-B.....	69,000	*w''b*	*w''b*	*w''b*	Little change
RB Her.....	37,500	*w''rb*	*w''rb*	*w''rb*	Little change

Method of Symbolism: The letters used in the above table refer roughly to the component intensities defined at the beginning of the present paper. The 'primes' are intended to indicate a *weakness* of the primed component *relative* to the others. Thus *gy* stands for a quality about equally green and yellow, *g'y* for one in which the yellow is considerably stronger than the green, and *g''y* for one in which it is far stronger. The quality orange is naturally symbolized by *ry*, and purple by *rb*. The component *n* (degree of darkness) is neglected in all cases, and *w* is used only when needed to indicate a lack of saturation greater than that normal to the given stimuli. Strictly speaking, of course, both *N* and *W* are components of all sensations, whether chromatic or achromatic.

General Results: The table shows that in those cases where the primary quality of the stimulus entirely disappears or becomes very weak, the intensity is greater than 50,000, and frequently than 100,000 candles per square meter. The stimuli which are weaker than 50,000 candles per square meter show relatively little change. The already familiar fact that *B* is the most stable of the color qualities is again revealed in this table.

The following generalizations may safely be made from the above described experiments. (1) Prolonged exposure of the retina to large chromatic stimuli of high, but not maximal, intensity is not accompanied by the disappearance of the hues characteristic of those stimuli or, necessarily, by a reduction of the brightness value of the sensation to that of a neutral mid-gray. (2) With such stimuli the qualitative change which does occur occupies a comparatively short time at the beginning of an exposure, after the end of which time a qualitative equilibrium becomes established. (3) When the chromatic stimuli employed are of exceedingly high intensity, complete disappearance of the characteristic hues may ensue. These disappearances occur soon after the beginning of an exposure, but they do not necessarily involve the abolition of all chromatic quality, and never mean a reduction of the sensation to the achromatic level of neutral mid-gray.

The preliminary experiments just described suggest very strongly that the equilibrium sensation in vision is not a monotonous gray but, instead, varies widely with the nature of the stimulus in connection with which the equilibrium is established. Of course we cannot be certain at the outset just how long it should take to bring the visual system to equilibrium under given conditions, but there are reasons for believing that in general the time should not be very great. The above experiments show that the sensory changes which follow the onset of stimulation at first involve a quite rapid decline of the characteristic stimulus quality; but although the alteration in the sensation during the first 30 or 60 seconds of the fixation is very readily perceived, that which takes place during the second minute (say) is—with ordinary light intensities—so small as to be hardly perceptible. Now it is just this sort of change which is demanded by a curve of the type presented in our equations (7) and (8) which, as we have seen, must go with such a chemical theory of vision as Hering's. However, there is a further qualitative consequence of the applicability of this form of equation to the phenomena which is not in harmony with Hering's teachings. If the

changes in sensation during a given constant interval of time are at first large, but rapidly become small, the total change occurring thereafter prior to the attainment of practically complete equilibrium, will also be very small compared with the initial changes. In other words, if for the consummation of the greater part of the change in sensitivity of the organ towards equilibrium a long time is to be assumed, it must be supposed also that a long time will be required for any alteration in the *rate of change* of sensitivity to occur. The mathematical explanation of this is apparent when it is noticed that all of the derivatives of the function $-ke^{-kt}$ (equation 7) with respect to t are equal to the function itself, and hence to each other.

If follows from this that, neglecting for the moment the effect of the function $f^d(\ )$ upon the changes, the fact of a rapid initial decrease in v, followed by a very slow decrease, indicates that the sensation reached in this brief preliminary period of fatigue is very close to the equilibrium sensation. Observation shows that in the majority of cases the approxmate equilibrium sensation thus obtained is very far from being a neutral mid-gray. Moreover, greatly prolonged fixation, as we should expect, brings about relatively little alteration in the quality which is left after the first few minutes of fatigue. As already noted, there are strong indications that, if anything, continued fixation may entail a reversal in the direction of the sensitivity change. In this event the fatigue is limited not by an asymptote but by a maximum, and the actual law of the adaptation process must involve functions either different from or in addition to that of equation (8). We shall return to this problem at a later point in the discussion.

With regard to the interpretation of the above results as a refutation of Hering's assumptions regarding the condition obtaining at visual equilibrium, several objections may be raised, some theoretical, some experimental. They all tend to throw doubt upon the notion that actual conditions of equilibrium were reached in the experiments described.

In the first place it may be asserted that the form of the function, f^d ( ) in equations (7) and (8) is such as to magnify changes in $-k\,e^{-kt}$ for large values of the latter and to minify such changes for small values, so that the time for the attainment of approximate equilibrium may really be great, although the apparent changes in the sensation are larger during the earlier than during the later parts of the fixation period. In answer to this it may be said that there can hardly be any doubt that f^d ( ) is logarithmic in general form—as demanded by Fechner's law relationship between the physiological visual process and the sensation—and that, consequently, its effect will be just the reverse of that required to weaken our argument against Hering. Equal changes in $-k\,e^{-kt}$ will produce smaller variations in v for high than for low values of the function in question.

Another objection, based upon experiment, may be drawn from the fact that if colored glasses are worn for a relatively long period of time, or if one is shut up in a room illuminated by a single color, one eventually becomes quite blind to the color in question. The experiment of Maria Bokowa[1] is classical in this connection. However, as previously indicated, there are strong reasons for believing that, besides visual fatigue in the ordinary sense of the term, we have in such phenomena as these to deal with a type of 'higher,' central alteration in sensation, such as is involved in the study of so-called 'memory colors.' When we are placed under the practical necessity of discriminating between objects for purpose of action we perceptually neglect all absolutely common qualities of these objects. Such perceptual neglect, or central adaptation may result, with sufficiently long exposure to a single color, in a nervous set which will remain for some time after the color is removed. This would involve blindness to the quality in question. The existence of a positive central control over the visual sensations cannot be denied.

[1] Bokowa, M., 'Ein Verfahren künstliche Farbenblindheit hervorzubringen,' *Zsch. f. rat. Med.*, 1863, 17, 161 ff.

IV. The Influence of Possible Central Factors on the Perception of Chromatic Qualities at Equilibrium

That central processes are actually involved in the fading of constantly fixated uniform color fields of large area is strongly suggested by the following observations.

Experiment III. The Restoration of a Chromatic Quality, Faded Through Adaptation, by the Introduction of a Neutral Comparison Object

If, during the intermediate period of the fixation of any of the large colored papers in Experiment II., a small white or gray object—such as the dial of a stop-watch—is introduced into the field, the original color is perceived with suddenly increased distinctness. The alteration in the appearance of the field is very remarkable, and yet it does not seem to be a purely sensory change: it lacks the characteristic *quale* of an objective alteration in illumination conditions and feels more like the reëstablishment of a decadent perception. This effect occurs for all the colors employed in Experiment II., regardless of the stimulus intensity. When the comparison object is introduced the color field turns darker at the same time that its original quality is again clearly distinguished.

In these experiments the comparison object is of course suffused with a color complementary to that of the original field, and hence the rejuvenescence of the latter quality would naturally be attributed to simultaneous chromatic contrast. It is clear, however, that with regard to the retina at least, the situation must be somewhat different from the usual case in which the contrast-inducing color depends upon the specific quality of the stimulus. Moreover, in the effect which we are now considering the contrast-inducing object is small compared with the field which it affects, and yet its influence is very striking. Its law would therefore appear to be quantitatively, if not qualitatively, different from that of ordinary color contrast. That the two cases are really distinct is proven by the following experiment. A dark gray square of size approximately 9 degrees, was placed in the center of the

yellowish green Hering paper, and was fixated in direct sun light until the green component had entirely faded, leaving a light blue—a state of affairs which continued for four minutes. At the end of this time a shutter arrangement was released which substituted in place of the gray square an equal area of Hering violet paper. Under these conditions there was no reappearance of the green, the outlying field becoming simply a somewhat darker blue. Immediately, however, a white object was introduced into the green adapted area, the latter color returned.

Simple tests were made to determine whether the reappearance of the adapted color might not be due to a contraction of the pupil, owing perhaps to the correction of a relaxed accommodation when the comparison object was introduced. In these tests an object of about the same brightness as the large field was employed, and care was taken to keep the fibers of the paper clearly in focus throughout. This made no difference in the results. As will appear later, it is probable that contraction of the pupil would tend to bring out the complementary quality rather than that proper to the field, although it is not entirely certain that this would be the case for the high degrees of illumination here employed.

The above experiments, while they support the view that color sensation is subject to central control, also indicate that 'central adaptation,' if it be a fact, can function as a local process, and hence is not strictly equivalent to 'forgetting what the color looks like.'

Experiment IV. The Equilibrium Sensation for Large Contrasting Colored Paper Fields

In order to study the importance of contrast and discrimination processes for the changes occuring in large fixated fields of color, observations under conditions similar to those of Experiment I., were made; the stimuli consisting of two juxtaposed Hering papers of different hue, the one filling the upper half of the field and the other the lower half. The six possible combinations of the four *Urfarben* were employed, and the results are shown in Table II.

An examination of the table in question will reveal the presence of a rather well marked mutual influence of the contrasting colors of the stimulus in the determination of the equilibrium qualities. This interaction appears to follow the law of ordinary complementary induction, as would be expected. For example, the red with the green loses less of saturation than it does with the yellow, while with the blue it becomes orange instead of pink. The green with the blue becomes yellowish, whereas with the yellow it turns toward the blue. The cases in which this complementary influence is smallest appear to be with the blue and with the yellow. This fact may be attributed to the much greater brightness of the yellow and greater darkness of the blue, as compared with the other two colors, or else to the well-known superior stability of the *Y* and *B* components, in general. The results of the present experiment would appear to support the conclusion that the principle of simultaneous color contrast applies to the equilibrium condition of the sensation, as well as to other phases. Whether this fact is to be attributed to central or to peripheral action is a question which must be considered an integral part of the still unanswered query as to the meaning of contrast, at large. From the writer's present point of view it seems to him probable that complementary color contrast in general is a central process, being one case of the sort of regulative activity of the centers with regard to the sensation quality already suggested above.

It must not be inferred from what has just been said that the results summarized in Table II. represent a contrast effect of the same order of magnitude as that considered in Experiment II. On the contrary, the introduction of a neutral object into the bi-chromatic field brings about the same striking change in quality, for both halves of the field, which occurs in the case of the simpler stimulus.

Observations under conditions exactly similar to those specified in Table II. were carried out with bipartite fixation fields composed of black and white—black velvet and white drawing paper—respectively. The intensity of the former was about 1,250 candles per square meter, and of the latter

TABLE II

THE FATIGUE CHANGES IN SENSATION WITH LARGE BICHROMATIC STIMULUS FIELDS OF HIGH INTENSITY

General Conditions: Size of stimulus fields: approximately 50° by 50°, the upper half being filled by one color and the lower by the other; Time of each fixation of the middle of the line of demarcation: 10 minutes. The papers were from the Hering series only. These were viewed in direct sunlight on cloudless March and April days, between 1 and 3 P.M. Subject: *T.* Monocular fixation.

Explanation of Tables: The arrangement of the table, and the symbolism employed is the same as for Table I., above. Brackets are used to indicate the pairs of stimuli fixated together in the double fields.

Stimulus	Intensity	Color Phase			Remarks
		Initial	Intermed.	Final	
Y.....	130,000	*y''g''w*	*ygw*	*ygw*	There was a short initial phase of nearly equal luminosity.
R.....	50,000	*r''w*	*rw*	*rw*	
R.....	50,000	*r'w*	*rw'*	*rw'*	
G.....	80,500	*w*	*g''b''w*	*g''b''w*	
R.....	50,000	*rgw*	*rgw*	*rgw*	
B.....	6,700	*bw*	*bw*	*bw*	
Y.....	130,000	*gy*	*g'y*	*g'y*	Same effect as for *Y* and *R*, above.
G.....	80,500	*b'w*	*b'w*	*b'w*	
B.....	6,700	*bw*	*bw*	*bw*	
Y.....	130,000	*gy*	*gy*	*gy*	
B.....	6,700	*bw*	*bw*	*bw*	
G.....	80,500	*w*	*yw*	*yw*	

approximately 250,000. At no time during the ten-minute fixation period was there even a tendency for the two halves to fuse in a common neutral mid-gray, as demanded by Hering's theory. The white became greatly reduced in apparent luminosity and assumed a bluish tinge during the first minute, but after that suffered no change, except possibly a slight increase in brightness. The black showed no change at all. Experiments were also made with a piece of white paper bearing a diffuse smudge of smoke—a pattern recommending by Hering for the demonstration of the lapse of visual differentiæ through fatigue[1]—which was fixated in bright sunlight. Momentary disappearances of the brown smoke spot were obtained, but these were always during the first minute or two after fixation. Even at the outset the

[1] Hering, E., 'Zur Lehre vom Lichtsinne,' *Sitzb. d. Wien. Akad.*, 1872–1874, 2 Aufl., 1878, p. 96.

smudge was a fairly bright gray, a fact which helps to account for its easy disappearance.

In all of the experiments thus far described the writer acted as subject.

The experiments described in the present Section offer a certain degree of confirmation for the idea suggested at the end of Section I. that the disappearance or weakening of some of the components of visual sensation may have central as well as peripheral causes, a procedure being pointed out whereby the original qualities can be restored without resting the retina. The success of this procedure appears to rest upon a central principle of color contrast. In line with this it is shown that the law of complementary color induction applies to the equilibrium, as to other, visual sensations.

V. The Fluctuation in Visibility of Spot Stimuli on a Dark Ground, and Related Phenomena

Suppose, now, that we pass from the consideration of the probable equilibrium conditions which go with large intensive stimuli of uniform quality to those obtaining with simple patterns in which the illumination is less intense. The simplest case is that of a small round luminous spot on a dark ground. A large number of investigations are already on record with regard to the course of the sensation conditioned by such stimuli, with constant fixation. It is a well-known fact that when the illumination of the spots is at low intensity they readily disappear, and either remain below the threshold or fluctuate between visibility and invisibility.[1] If the dark outlying field could be considered as a neutral mid-gray, this would present a case of the complete reduction of a sensation by adaptation. These disappearances also occur when the intensity of the stimulus is moderately high, but they are less frequent and last a much shorter time than with the dim lights. The general law appears to be that the phase of visibility increases at the expense of that of invisibility with increasing intensity.[2] For very low intensities disappearance may be

[1] Ladd, G. T., 'A Color Illusion,' *Yale Studies*, 1898, 6, 1 ff.

[2] Marbe, K., 'Die Schwankungen der Gesichtsempfindungen,' *Phil. Stud.*, 1893, 8, 615-637.

permanent, if the spot is not too small, but for very high ones it never occurs in the first place.

These fluctuations of visual sensation under the influence of a constant external stimulus receive ready explanation in terms of the Hering theory, if it is supposed that slips of fixation occur, during which a rapid change in the state of adaptation of the visual system can take place. If, prior to the eye-movement, the visual cells were at equilibrium with the stimulus, the field of sensation must have been a neutral mid-gray, but as soon as the ocular displacement occurs, differential recovery sets in so that upon a return to the original fixation the spot is again momentarily seen. Ferree[1] has reported experiments in support of this interpretation of the fluctuations. The Hering theory of the mid-neutrality of the equilibrium sensation, however, does not account for the relation of the relative lengths of the phases of visibility and invisibility to the intensity of the stimulus, although it is directly in harmony with the fact, adduced by Ferree, that for certain low intensities very small areas show no disappearances while very large ones disappear permanently.[2] The imperfectness of fixation always suffices constantly to present fresh retinal surfaces to a very small stimulus spot. For complete harmony with the theory, the rule of disappearance, without return, of large areas should hold for all intensities.

The fluctuations in the gray bands presented by the classical Masson's disk have, for a long time, been attributed to momentary 'lapses of attention,'[3] in spite of the obvious fact that under the usual conditions of the experiment, attention to the disk is probably maximal at just the moments of disappearance of the bands. Heinrich and Chwistek,[4] and others, have sought the cause of the fluctuations in spon-

[1] Ferree, C. E., 'An Experimental Examination of the Phenomena Usually Attributed to Fluctuation of Attention,' *Amer. J. of Psychol.*, 1906, 17, 81–120.

[2] Ferree, C. E., 'The Intermittence of Minimal Visual Sensations,' *Amer. J. of Psychol.*, 1908, 19, 59–129.

[3] Lange, N., 'Beiträge zur Theorie der sinnlichen Aufmerksamkeit und der activen Apperception,' *Phil. Stud.*, 1888, 4, 390–422.

[4] Heinrich, W. und Chwistek, L., 'Ueber das periodische Verschwinden kleiner Punkte,' *Zsch. f. Sinnesphysiol.*, 1906, 41, 59–74.

taneous changes in lens accommodation, a quest which appears in the light of later investigations to have been in vain.[1]

Experiment V. The Dependence of the Time of the First Fluctuative Disappearance upon the Intensity of the Stimulus

That these fluctuative disappearances of sensations caused by constant stimuli actually have the adaptation process as at least a partial basis is strongly suggested by the following experiment. A white circle, of visual angle approximating 4°, was fixated monocularly in the dark (by subject *T*) and the time from the beginning of the fixation until the occurrence of the first fluctuation was measured. When the light was at low intensity the average of four trials gave 15 seconds (A.D. 1.6) for the first disappearance, and 24 seconds (A.D. 1.9) for the second, an interval of 9 seconds between the two. At a considerably higher intensity the first disappearance occurred at 116 seconds (A.D. 27, in an average of 4 trials) and the second at 153 (A.D. 27), an interval of 37 seconds. Four minutes complete dark adaptation was allowed between each trial.

The intensities of the lights employed in these experiments were not measured but the significance of the results is, nevertheless, obvious. The much longer time which is required for the brighter as compared with the duller light to show its first disappearance must be referred to the longer period needed for adaptation to bring the corresponding sensation near enough to the threshold for disappearance to be possible. Once this lowering of the potential of the visual cells has been accomplished, however, a second disappearance can occur without the lapse of an equal period.

After visual equilibrium has been reached, the frequency at which the disappearances take place will be determined by secondary causes, the most important of which will be considered shortly. If the equilibrium sensation is not a

[1] Ferree, C. E., 'The Fluctuation of Liminal Visual Stimuli of Point Area,' *Amer. J. of Psychol.*, 1913, 24, 378–409.

neutral mid-gray, and if its brightness is in some sense proportional to the intensity of the stimulus, the disappearances might be expected to be more frequent for the lower than for the higher intensities. With the 2° white stimulus at an intensity still higher than in either of the cases considered above, subjects *H* and *E* failed to observe any disappearances during continuous fixation periods of 30 minutes. Similar results were obtained with subject *E* when the spot was viewed for 30 minutes through a ruby red glass. At higher intensities the sensation from this latter stimulus was readily reduced to a pure yellow. A large number of experiments were carried out with a very bright red stimulus—containing only the orange and red of the spectrum—of visual angle approximating 6.4°, in which the fixation periods were varied from 7 to 10 minutes. Although the subjects (*E*, *H*, and *T*) reported apparent sensory equilibrium within 30 seconds to 4 minutes no cases of disappearance were observed. With a somewhat weaker light there was no disappearance even of the *R* component of the sensation. Similar results were obtained with a green stimulus of the same dimensions, except that no instance of complete disappearance of the green component was reported in the few trials made with this color.

VI. The Influence of the Size of the Pupil on the Visibility of Stimuli

The theory of Hering would explain the fluctuative disappearances of spot stimuli by complete reduction, through adaptation, of the original sensation to a neutral mid-gray. The fluctuations would then be regarded as *reappearances* due to eye-movement[1] or other external causes, which permit momentary phases of reversal of the adaptation (recovery). However, the force of this explanation obviously is gone if the conception which we have been attempting to support in the foregoing general argument be admitted, *viz.*, that equilibrium adaptation does not bring all sensations to a common level regardless of the nature of the stimuli which

[1] Ferree, C. E., 'An Experimental Examination of the Phenomena Usually Attributed to Fluctuation of Attention,' *Amer. J. of Psychol.*, 1906, 17, p. 83 ff.

cause them. The Hering explanation holds for sensations whose equilibrium levels place them beyond the possibility of discrimination with respect to the idioretinal gray, but not for those possessing a higher equilibrium than this. The question remains to be answered therefore as to whether fluctuations actually occur with such stimuli as the latter.

On the not rigidly critical plane of argument upon which we now stand, a method for the solution of this problem immediately suggests itself. As already noted, Ferree has shown that large angle stimuli of low intensity disappear and do not return.[1] This is due to the fact that eye-movements are too small to free the retina from continued stimulation, so that no opportunity is offered for 'recovery.' Such stimuli condition an equilibrium sensation which lies below the threshold. It is clear, then, that if a stimulus of large angular area disappears and then returns, while fixation remains as nearly as possible stationary, its disappearance cannot be a simple matter of 'fatigue' and 'recovery,' on any basis yet considered. If eye-movement is the only ocular change which can permit 'recovery,' any stimulus of large area which returns to visibility after a disappearance must have a *supraliminal equilibrium sensation.*

Experiment VI. The Fluctuation in Visibility of Large Colored Paper Stimulus Fields

That such large stimuli actually do show fluctuations can easily be proven. A half sheet of Hering red paper was arranged so as to give a stimulus of visual angle 35° by 24°, a dark fixation circle being provided in the middle. This was illuminated so as to have an intensity of three candles per square meter (as measured by the flicker photometer, subject *T*). With steady fixation, repeated fluctuations in the brightness of the field, with frequent, although momentary, complete disappearances, were observed by five subjects (*T*, *D*, *B*, *S*, and *M*) to whom the stimulus was presented. After heavy darkenings the field reappeared with even augmented brightness, and during fixation periods of 10 minutes and

[1] *Ibid.*, p. 85.

more, no *permanent* disappearance could be obtained, the actually observed obscurations being very brief. The stimulation was monocular, the other eye being heavily blindfolded.

Fluctuations of this sort obviously cannot be explained on the basis of complete fatigue followed by recovery due to eye-movement, because, under the conditions, deviations in fixation would not move the image on the retina through much more than one fiftieth of its total diameter. Changes in accommodation, also, could exert no influence on the course of the sensation, since with large uniform stimulus surfaces they could produce only edge effects upon the image. There exists, however, a very potent factor in the limitation of the action of an external stimulus upon the retina which, for some unexplained reason, has received comparatively little attention in general visual experimentation, namely, *the size and activity of the pupil.*

The diameter of the average human pupil is capable of variation from a maximum of 7.5 mm. to a minimum of 1.5 mm., although the usual aperture lies between 2 and 6 mm. Since the amount of light entering the pupil varies as the square of its diameter the intensity of a retinal image which, with a maximal pupil is 1, will with a minimal pupil be 1/25, *i.e.*, with the former an external stimulus intensity of one candle per square meter is visually equivalent to a stimulus intensity of twenty-five candles per square meter with the latter. Now although the size of the pupil is for the practical purposes of seeing a function of the external illumination, this size is by no means invariant during steady stimulation, oscillations as great as 2 mm. being quite common. All changes in the size of the pupil which occur in the presence of such stimulation must of necessity have an effect upon vision which is identical with that to be produced by actual variation in the stimulus intensity. That such variations are ideally fitted to cause fluctuative disappearances of the type we have just been discussing, a moment's consideration will suffice to show.

In his earliest writings Hering[1] pointed out that the dimming of a fixated stimulus field, which had been acting upon the retina for some time previously, might not only cause the stimulus to disappear visually, but, if the reduction in intensity were sufficiently great, might bring about a replacement of the original quality by its antagonist. This phenomenon is a well authenticated one, and has been studied in considerable detail by the present writer for certain special cases (which will be discussed in a subsequent article). For purposes of discussion it may be referred to as the *dimming effect;* and it clearly represents one aspect of the generation of the negative and complementary after-image. It is clear that this effect can follow as readily from a contraction of the pupil as from the turning down of a lamp or the closing of a shutter.

Experiment VII. The Correlation of Movements of the Iris With Visual Fluctuations

In order to determine empirically whether the fluctuations occurring in the visibility of stimuli supposed to have a supraliminal equilibrium sensation can actually be attributed to pupillary contractions and expansions, the following experiments were made. The stimulus surface last described above was perforated at the fixation spot, and a reading telescope was placed behind it in line with the perforation and the eye of the subject, who was provided with a signal key. In this way the subject's pupil could be observed at the instant when disappearances of the stimulus were reported by a depression of the key. Observations on five subjects (*T*, *M*, *B*, *D*, and *S*) were made with this arrangement, the iris being illuminated no more than necessary to permit its movements to be clearly seen through the telescope.

The results of these experiments leave no doubt that pupillary contractions and expansions are a primary cause of the fluctuation of stimuli, which have a supraliminal sensory equilibrium. In every series of observations striking coin-

[1] Hering, E., 'Zur Lehre vom Lichtsinne,' *Sitzb. d. Wien. Akad.*, 1872–1874, p. 132.

cidences between pupillary contractions and the disappearance signals were noted. Practically every strong contraction was followed immediately by a signal. The best conditions for observation appeared to exist when the activity of the pupil became rhythmic. As a sample of the results obtained, the following trial with subject *D* may be described. At the beginning of the fixation the pupil had a fairly large opening, about 4 to 5 mm., and showed some fluctuations rather difficult to follow. During the preliminary period the subject gave some disappearance signals for which a clear correlation with pupillary action could not be affirmed. After the lapse of an interval which would seem to correspond roughly with the time required for the retina to reach sensory equilibrium, the pupil began rather suddenly to show sharp rhythmic contractions, in which the diameter changed from about 4 to about 2 mm. During a continuous series of twenty of these contractions there was only one for which the subject did not give a signal at an interval of 2/5 to 3/5 of a second after its completion, a period which corresponds very closely to that required to produce the dimming effect. The subject reported each time the (Hering red) color wholly disappeared from the field of vision. After a rest the observations were resumed, with exactly similar results in every respect. These two series then give 38 cases of perfect coincidence between pupillary contraction and disappearance of the stimulus, out of 40 cases of observed contraction, and during the periods of easily observable contractions there were no cases of disappearance which were unaccompanied by the pupillary change. The subject stated that the disappearances which occurred in the preliminary periods of small fluctuations were not as well marked as those which followed.

There appears to be evidence in these observations of a definite rhythmic reflex of the pupil, the biological significance of which may perhaps lie in the possibility of producing clear intermittent vision where satisfactory continuous vision is impossible owing to adaptation. The contraction of the pupil will have an effect similar to that attributed to eye movement in the case of small luminous stimuli, and permit the retina

to recover, so that in the succeeding phase of dilation vision is again restored. Such a mechanism would of course apply primarily to stimuli of subliminal sensory equilibrium although it would not be limited to these. The assumption of its existence is not necessary to validate the general argument regarding fluctuations in visibility which we are here presenting, since wavering aperiodic activity of the iris is an unquestionable fact.

An interesting variation of the above experiment is the following. The experimenter informed the subject that he would tell him how the stimulus field looked to him (the subject) from time to time. This the experimenter did by inference from the pupillary size at the moment. Thus, when the pupil was large he inferred an apparent brightness of the stimulus, with contraction he stated that it was now darkening, etc. At the end of a three-minute experiment of this sort the subject (*B*) reported that not more than three mistakes had been made in the 'predictions' of the experimenter.

In these experiments the writer several times exchanged places with his subject, with a confirmation of the above described results in all essential particulars. Limitations of time did not permit the application of a more objective method for recording the pupillary changes contemporaneously with the disappearance signals, a development of the research which is of course desirable.

The correlation between disappearance and obvious pupillary contraction is not perfect. When the activity of the iris was of the wavering type a considerable number of signals were given by the subject for which the experimenter noted no distinct contractions, and on the other hand, there were many contractions for which no signals were given. The latter point is not of great importance, since whether or not a contraction produces a disappearance will depend both upon its magnitude and upon the exact state of adaptation at the moment, and it must be kept in mind that with an active pupil this state of adaptation is by no means constant even in the presence of a constant external stimulus. With regard

to the report of disappearances when no contractions were observed, it may be said in the first place that, except where the changes in pupillary size have a considerable amplitude, they are not easy to record by the method of observation here employed, yet states of adaptation may occur where a small contraction will suffice to cause a disappearance. Contractions which start with a wide pupil, if themselves small, do not alter the intensity of the retinal stimulus by a large fraction, but they may nevertheless be effective in producing disappearances, owing to the fact that they act upon the basis of a strong prior 'fatigue.' On the other hand, linearly small contractions which start with a narrow pupil cause a relatively large change in the illumination of the retina.

It is a well-known fact that, in the so-called accommodation reflex, the pupil undergoes contraction simultaneously with the adjustment of the lens of the eye for near vision. Consequently the observations reported by other investigators which go to show that changes in accommodation coincide with phases of disappearance of visual stimuli, may receive an interpretation in terms of the activity of the iris. For stimuli of very small area, any accommodation change which causes blurring may produce a dimming effect by spreading the light out over a larger area. However, the probable efficacy of this change in the production of disappearances is doubtful, on account of the fact that this same process of spreading brings the light to fresh retinal surfaces, and it is a well-known fact that for small areas the threshold depends upon the total light energy received rather than upon the illumination. The effect would be limited in any case to very small stimuli.

In their crude outlines the above reported experiments do not prove that the stimuli which were observed to fluctuate were actually of supraliminal sensory equilibrium, since it is obvious that a stimulus which disappears through simple fatigue may be brought once more to visibility through a dilation of the pupil—the effect of which upon the retina is the same as brightening the stimulus. This will be true especially if the dilation is preceded by a contraction. How-

ever, the fact that, in the experiments described, the subjects' signals practically always followed the pupillary contractions by a considerable interval rather than *vice versa*, would seem to indicate that the disappearances were caused by the contractions and not the contractions by the disappearances. If this is the case the disappearances must have been of the dimming effect type and the stimuli, consequently, of supra-liminal sensory equilibrium. Another fact which supports this latter interpretation of the results lies in the momentary character of the disappearances, which was paralleled by the almost instantaneous redilation of the pupil. Long periods of visibility compared with those of invisibility would appear to indicate that the former represent the equilibrium state of the organ. As will be shown later, the effective intensity of the 3 candles-per-square-meter stimulus used in the above experiments is about ten times that of the minimal stimulus which, with the artificial pupil, shows no disappearances.

It is obvious that with stimuli of high intensity, for which the pupil has attained its maximum contraction, a pupillary dimming effect is impossible. This consideration harmonizes with the fact, which was pointed out in section III, that disappearances of stimuli of high intensity do not occur.

VII. Observations and Measurements Upon Equilibrium Sensations With the Use of the Artificial Pupil

The crucial test of the theory that the primary cause of the fluctuations in visibility for other than minimal stimuli is to be found in pupillary contraction and expansion would seem to lie in the elimination of these changes either by atropinization or by the use of an artificial pupil. Experiments have already been carried out by Pace[1] and McDougall[2] in which the eye muscles were atropinized, although the primary object of the treatment was apparently to paralyze the ciliary muscles rather than those of the iris. Both of

[1] Pace, E., 'Zur Frage der Schwankungen der Aufmerksamkeit nach Versuchen mit der Masson's Scheibe,' *Phil. Stud.*, 1893, 8, 388–403.

[2] McDougall, W., 'The Physiological Factors of the Attention Process,' *Mind*, 1903, 26, p. 476.

these observers reported fluctuations. However, their methods of work were not such as to yield conclusive results with regard to that sort of influence of the pupil in which we are now interested, McDougall's primary interest being in retinal rivalry phenomena. Consequently further work along these lines would seem to be desirable. The employment of the artificial pupil provides a better means for the elimination of pupillary effects from the adaptation process in vision than do the drugs, atropin and pilocarpin. Such a pupil, of diameter 2.36 mm., was used by the writer in all of the measurements to be described below. In the course of these measurements several thousand observations of spot stimuli of medium brightness—ranging in size from .7° to 3.5°—on a dark ground, with fixation periods varying from one to 15 minutes, were made, and the number of fluctuative disappearances which were seen could be counted on the fingers of one hand. This would appear to be conclusive proof that the variations in size of the natural pupil are the essential cause of these disappearances, when the pupil is free to modify the intensity of the retinal stimulus.

The above statement applies only to stimuli of moderate or of high intensity, and not to those of very low intensity. If the latter are what we have designated as 'of subliminal sensory equilibrium' it is obvious that adaptation will cause their disappearance, and that when their equilibrium sensations lie very close to the threshold,[1] slight disturbances, such as slips of fixation, changes in the nutrition of the retina, etc., will cause them to fluctuate in visibility.

Experiment VIII. Measurement of the Minimal Stimulus Intensity Necessary to Prevent Fluctuative Disappearances with the Artificial Pupil

In order to determine the intensity of such an equilibrium threshold stimulus the following experiments were made. The results apply, of course, only to the special conditions under which the measurements were taken, *viz.*, for foveal vision with a dark contrast field.

[1] The threshold concept throughout this paper is clearly differential as well as absolute.

The stimulus employed in each case was in the form of a circular spot 83 cms. distant from the eye of the subject and of angular diameter 1.28°, which, on the basis of the estimates usually given, could be counted upon to stimulate only retinal cones, in the normal subject. In the case of the blue and the green, where signs of a photochromatic interval appeared, a field of size .69° was also employed. In the center of the field was placed a dark circular fixation spot of angular diameter .18°. The lights employed in these fields consisted of radiation selected and controlled by a spectrometer system. The four wave-length groups, used, corresponded approximately to the subjects' four psychological primaries, *R*, *Y*, *G*, and *B*, and the flicker equations upon which the candles-per-square-meter values in Table III. are based were made by the same subjects (*S* and *T*).

These observations and all subsequent ones in which spot stimuli were employed were carried out in a room which, as regards the vision of colors, could be considered practically dark. What little diffuse light there was present was prevented from affecting the stimulus field or acting on any but the extreme peripheral parts of the retina during the observations. The periods of rest given to each eye after an experiment before it was used again were adequate to insure a return to maximal color sensitivity.

In the present experiment the intensity of the spot stimuli was under the control of the subject, who was instructed to fixate the black mid-point and, starting with a very low intensity, to increase the brightness slightly every time a disappearance occurred. The time of each disappearance was noted, and when none was reported during a three-minute interval the stimulus was regarded as of the required threshold intensity. At least four successive determinations of this sort were made upon each color. The corresponding voltage readings on the spectrometer lamp were then averaged and the intensity of the field corresponding to this average was photometered. The final results are given in Table III.

As shown in the table it was easy to find a point at a low intensity for which no disappearances of the spot occurred.

In the case of the red and yellow the stimulus retained its original color, in good saturation, at the intensity in question. With the green and blue, however, there was a strong tendency for it to pass over into a gray before disappearing. This well-known phenomenon of a photochromatic interval in the case of lights of the shorter wave-lengths, made it necessary to modify the experimental method for stimuli of this sort so that the threshold intensity value finally found was one for which the *color* remained constantly visible, although a considerably lower value might have sufficed to keep the spot in view as a gray. The photochromatic interval is usually supposed to be absent with strictly foveal stimuli,[1] and the few observations here reported cannot be regarded as adequate to refute this view, since slight slips of fixation easily bring the stimulus into the extra foveal region when it has fallen below the threshold in the fovea itself.

The observations and measurements just described show that if the action of the iris is eliminated, a stimulus of low intensity is able to maintain a steady sensation without loss of its proper quality for long intervals. The periods of time employed are probably sufficiently protracted to justify the assumption that the measurements apply to the equilibrium sensations of the stimuli which were used. These results, then, argue very strongly against the Hering view that equilibrium sensations are a uniform neutral gray, and in combination with facts previously considered constitute proof of the efficacy of the natural pupil as a cause of visual fluctuations.

The fluctuations which are actually observed near the threshold are probably somewhat complex in their causation. Some of them are no doubt to be explained on the eye-movement-recovery theory, either in its ordinary form or with respect to the influence of these movements on the amount of light entering the eye through the artificial pupil. Large deviations from 'register' (co-centering) of the natural and artificial pupils cut off some of the light and this produces a dimming effect. Registration was secured at the beginning

[1] Nagel, W., 'Adaptation, Dämmerungssehen und Duplizitätstheorie,' *Helmholtz's Physiol. Opt.*, 3 Aufl., 1911, 2, p. 309.

TABLE III

THE VALUE OF THE EQUILIBRIUM THRESHOLD STIMULUS FOR FOUR SPECTRAL LIGHTS, WITH AN ARTIFICIAL PUPIL

General Conditions: Size of stimulus field: 1.28° in diameter (circular), dark fixation point: .18° in diameter; Total time of each fixation: about 15 minutes; Standard time during which the spot must show no disappearances of color in order that the intensity should be taken as a threshold: 3 minutes; Diameter of artificial pupil: 2.36 mm.; Fixation, monocular, the other eye being blindfolded.

Explanation of the Table: In the first column, below, are given the wave-length ranges employed, in $m\mu$. The second gives the thresholds in candles per square meter for the two subjects *S* and *T*. The numbers in parenthesis represent the intensity of the stimulus in photons or the product of the candles-per-square-meter value and the millimeter area of the artificial pupil. The threshold values themselves are given under "Av." and are the average of at least four separate determinations. Under "A.D." is given the estimated average deviation of the mean, independent of photometric errors, which may amount to 2 percent, and the 5 percent uncertainty involved in the reproduction of the Hefner amyl acetate standard.

Radiation Range, $m\mu$	Threshold Intensity in C. per Sq. M.				Color
	Subj. *S.*		Subj. *T.*		
	Av.	A.D.	Av.	A.D.	
690.2–705.8.....	.436 (1.90)	.021 (.09)	1.088 (4.75)	.045 (.20)	*R*
580.0–587.6.....	.85 (3.71)	.54 (2.4)	.94 (4.10)	.13 (.57)	*Y*
525.4–530.0.....	1.782 (7.77)	.018 (.08)	.94 (4.10)	.13 (.57)	*G*
451.2–455.8.....	2.09 (9.11)	.12 (.52)	1.50 (6.54)	.23 (1.0)	*B*
General average....	1.29 (5.63)		1.12 (4.78)		

and tested at the end of each trial in the above series by a method described elsewhere.[1] So far as the writer's own observations are concerned, however, it appears to him probable that the fluctuations of liminal color fields should be attributed to that sort of disturbance in the nutrition or electrical condition of the visual system which goes with the undulations in the idio-retinal light. Ferree's[2] observations in this respect

[1] Troland, L. T., 'The Theory and Practice of the Artificial Pupil,' *Psychol. Rev.* 1915, 22, 172–176.

[2] Ferree, C. E., 'The Streaming Phenomenon,' *Amer. J. of Psychol.*, 1908, 19, 484–503.

seem to him correct, since by far the greater number of disappearances of such color fields involve a submergence of the spot in one of these bright surgings. Another cause is probably binocular rivalry with the opposite wholly dark field. It is clear that the above measurements of the equilibrium threshold, which indicate an average value of about 1.2 candles per square meter with a pupil of 2.36 mm. are not minimal, because they indicate a factor over and above that required by considerations of pure adaptation, which is necessary to counterbalance the disturbing influences just mentioned. Moreover, it would be absurd to claim that, with prolonged fixation, cases might not arise in which this factor would have to be increased considerably.

Experiment IX. The Equilibrium Sensation for Spot Spectral Stimuli of Equal Brightness, with the Artificial Pupil

The experiments just described were extended in a series of observations made by subject *B* in which spectral stimuli of angular size 1.28°, only, were used, with fixation conditions similar to those in the first series. Eight lights were employed which were equated in respect of brightness by means of the flicker photometer, the common intensity being 44.7 candles per square meter, an artificial pupil of 2.36 mm. being utilized, yielding a photon value of 195.1. The ranges of wavelengths employed were the four used above, together with a violet, blue-green, yellow-green, and orange. The flicker equations were made by subject *L* for another purpose, and were not verified for subject *B*, because of limitations of time and the fact that both were thoroughly normal in their color vision, subject *L* having himself done extensive work upon color. The results of the ten-minute monocular fixation of these stimuli are given in Table IV.

The primary object of this series of observations was to determine whether spot stimuli of moderate intensity show radical changes in apparent quality at sensory equilibrium. The results indicate in the first place that with the artificial pupil no disappearances of such stimuli occur, and that even

Table IV

The Fatigue Changes in Sensation with Small Spectral Stimuli of Equal Moderate Brightness, with the Artificial Pupil

General Conditions: Size of stimulus fields: 1.28° in diameter (circular), dark fixation point: .18° in diameter; Total time of each fixation: 10 minutes; Diameter of artificial pupil: 2.36 mm.; fixation: monocular, in the dark; Common intensity of the stimuli: 44.7 candles per square meter, or 195.1 photons. The precision of these and subsequent photometric measures is about 2 percent as regards the standard (the Hefner, Reichsanstalt, amyl acetate lamp) used by the writer, and about 5 percent as regards the general reproducibility of this standard. The precision of reproducibility of the stimulus fields varies from 0.5 percent to about 2 percent. The precision measures are expressed in terms of candles per square meter. Subject: *B.*

Explanation of the Table: The arrangement and symbolism in this table are similar to those in Table I., *q.v.* The first column gives the wave-length range of the stimulus.

Radiation Range and Color	Color Phases			Remarks
	Initial	Intermed.	Final	
R 690.2–705.8	*r'y''w*	*r''w*	*r'w*	
RY 605.6–615.0	*r''y*	*r'w*	*r'y*	
Y 580.0–587.6	*y''w*	*y'w*	*yw'*	Strong return of yellow.
YG 552.0–558.0	*y*	*g''y*	*g''y*	Green wholly gone at first.
G 525.4–530.0	*yg*	*g'y*	*y'g*	
BG 487.4–494.4	*g''bw*	*g''bw*	*g''bw*	
B 451.2–455.8	*bw*	*bw*	*bw*	Not much change.
Vi 407.2–417.6	*b'w*	*b'w*	*b'w*	Red component permanently disappears.

very long fixation periods do not entail a reduction of the sensory quality to median or any other sort of gray. They indicate, moreover, that in the case of the psychological primaries there is no loss of the essential hue. The intermediate tones, however, may easily lose the *R* and *G* components, especially when the latter are relatively weak at the outset. The violet entirely lost its *R*, which did not return. The orange, which at the start was strongly reddish, showed marked diminution of this quality, but never lost it entirely. The blue-green always retained a slight tinge of green, and the yellow-green, while at the end of one minute it became pure yellow, during the last five minutes of the fixation showed a perfectly clear greenish tone. One of the most interesting results of the present series, therefore, is the confirmation which it provides of the observations made by subject *T* on

adaptation to large fields of stimulation, *i.e.*, that not only is the maximum depression of the sensation reached quickly (in one to three minutes), but that after this time there is a revival of the original quality.

During the course of the work with the method of critical flicker frequency to be described in a second paper, a considerable number of long interval fixations of the same spectral colors used above were carried out. The light in these cases was interrupted at the rate of 25 alternations, of equal light and dark periods, per second, the brightness of the stimulus being, during the greater part of the time, very close to that required to eliminate flicker at this frequency, approximately 30 candles per square meter. The fixation periods were nine minutes or more, subject *T* being the observer. The dimensions of the stimulus spot were the same as specified for the series just described. At least four cases with each color, two for each eye, were recorded. The results were that the only stimuli completely to lose any of their characteristic components were the violet and the blue-green, which lost their *R* and *G*, respectively, both becoming a whitish, unsaturated blue. All of the colors of course became less saturated and darker. The *G* component did not disappear from the yellow-green or the *R* from the orange. The red became slightly bluish instead of yellowish. The longest cases of fixation were of the red for 30 minutes, of the green for 21, and of the blue for 15. It is worth noting that practically no after-images were visible at the end of these long fixation periods, when the stimulus was removed and the eye left in the dark. This latter observation was repeatedly verified by subject *H*.

Experiments were not made with spot stimuli of high intensity, since the phenomena which they exhibit are quite well known. 'Fatigue' and increased intensity coöperate to extinguish, first, the *R* and *G* components in the sensation and then all chromatic elements, so that the stimulus appears white. This occurs with pure spectral lights at sufficiently high intensity, as well as with heterogeneous chromatic stimuli.

Hering's theory of color adaptation is inconsistent with the notion that a visual quality once below the threshold should return without alteration in the intensity of the stimulus. This statement would hold also of the doctrine which the present writer favors, provided the stimulus in question is the one under the influence of which the sensation originally disappeared; that is, if this stimulus is one of subliminal sensory equilibrium. But upon Hering's assumptions all stimuli are of this character.

Suppose that the retina is stimulated for some time, less than that necessary to produce equilibrium, by a light of relatively high intensity. This, in the words of Hering, will cause a lowering of the 'potential' of the visual cells. If, now, the light is dimmed, the sensation will easily fall below the threshold and may even be replaced by its antagonist. Under these conditions, if Hering's hypotheses are valid, the sensation cannot again mount into consciousness, since either the sense-cell is already at equilibrium with the stimulus of lowered intensity or the equilibrium condition will be approached from the side of the antagonist of the original sensory quality.

Experiment X. The Reappearance of a Visual Quality, Lost Through Adaptation, under Continued Stimulation

To test this issue, experiments were made with the four primary spot spectral stimuli used in Experiment VIII., the usual artificial pupil being employed. The greater part of the work was done by subject *S*, but his observations were corroborated by subject *T*.

The eye was first exposed for 20 seconds to a stimulus of about 30 candles-per-square-meter intensity (artificial pupil: 2.36 mm.), followed by a rapid decrease in the intensity, until the subject signaled that the spot had disappeared. Fixation was kept as nearly as possible constant by means of the bright crescents appearing at the edges of the adapted area and a signal was given when the whole area of the field came again into view.

The point to which it was necessary to reduce the intensity of the stimulus before disappearance occurred, depended upon

the original brightness and the time of preëxposure. In all cases the spot reappeared almost immediately, and remained visible thereafter as long as fixation was continued. In the case of the blue the reappearance was often that of a gray rather than a blue spot. The quantitative measurements made upon these phenomena were insufficient to permit any very secure generalizations, but they strongly suggest the view that regardless of the degree to which a specific sensitivity of the visual cells has been reduced by prior stimulation, this specific sensitivity will automatically readjust itself to a succeeding stimulation, with an end result which is practically independent of the preliminary 'fatigue.' The experiment proves, in general, that Hering's doctrine of the neutral median character of all equilibrium sensations cannot be true, since in these observations the movement towards equilibrium may be away from the neutral mid-gray and in the direction of the quality proper to the stimulus.

Objections to the above conclusions, based on the notion that recovery here may have taken place during an eye-movement incident upon the subjective disappearance of the stimulus spot, cannot be admitted, since lapses of fixation were easily guarded against by means of the bright crescents which they yielded on the edges of the fatigued area. The process of recrudescence of the sensation could be clearly observed to occur within the border defined by these crescents. With care, a practiced observer can maintain his fixation of a circular spot of the size here employed, to within about one sixteenth of its diameter.

VIII. The Influence of Binocular Rivalry upon the Visibility of Monocularly Viewed Stimuli

The work with the artificial pupil which has been described above shows that the liability of specific visual qualities to suffer extinction through processes of adaptation is much less than is commonly supposed. The experiments indicate very clearly the preëminent importance of pupillary fluctuations in bringing about the much-discussed fluctuative disappearances of visual areas. However, it would be folly to claim

that the contractions and expansions of the iris are the only changes which can aid such disappearances. Certainly other factors are operative, and among these, although its conditions of operation are somewhat special, is the process underlying retinal or binocular rivalry. A large number of very interesting observations by McDougall[1] reveal the importance of this mechanism in causing visual fluctuations, and give clear indications that it is not without effect even upon supposedly monocular vision. In the majority of exact studies of visual sensation it is necessary to stimulate only one eye, the other being in the meantime blindfolded. From a formal point of view this situation appears favorable for rivalry phenomena, since the two fields of vision are qualitatively different. However the dark gray of the blindfolded eye appears at most to have but a weak tendency, if any, to oust the quality of the opposite visual field from consciousness. As shown by the following experiments there are conditions under which this impotency of the non-externally stimulated field disappears.

Experiment XI. The Binocular Interaction of an Adaptation After-effect with the Original Stimulus

The following observations were made by subject *B* under the conditions specified in Experiment IX. After a long preëxposure of one eye to the spectral spot stimuli described above, it was found that if the stimulus was immediately transferred to the opposite eye it at first appeared of the proper color, but as soon as fixation was established it became a sparkling white, which gave place rather gradually to the proper quality. This effect was obtained several times each with the *R*, *Y*, *G*, *YG*, and *BG*, but not with the *B* or *Vi* stimuli. In the case of the orange a similar phenomenon was observed, in which, however, the crystalline appearance was tinged with yellow. With the green the whiteness changed after the lapse of a few seconds to a pure yellow, which persisted for a long time. In the other cases it was replaced after about 20 seconds by the normal stimulus

[1] McDougall, W., 'Some New Observations in Support of Thomas Young's Theory of Light and Color Vision,' *Mind*, 1901, 26, 52–98, 210–245, 347–382.

quality. The white was described as very brilliant and possessed of the characteristics common to binocular luster, so that the idea is clearly suggested that it was the result of a central combination of the after-image process of one eye with the primary image of the other, to form a complementary white. Time did not permit a careful investigation of this phenomenon to determine whether or not it could be obtained with blue and violet under the right conditions.

In the course of the work with large colored stimuli described in Experiments I. and II., it was found by subject *T* that if, after prolonged fixation with the right eye, the left eye was exposed to the stimulus and the right blindfolded, strong periodic darkenings, characterized by a pebbly pattern and a tinge of the hue complementary to the stimulus, appeared in the field. These darkenings were very patchy—and seemed generally to omit the foveal region—but where they occurred they entirely obscured the stimulus. If after a short fixation period with the left eye, the observation was continued once more with the right, similar surgings of the field were observed, except that in this case they were usually not darkenings, but consisted of strong patches of a color different from that of the stimulus. As in the case of the left eye the patches entirely supplanted the proper quality of the stimulus, except when—following the procedure of Experiment III.—a neutral comparison object was introduced, which permitted the original quality of the stimulus to be perceived through a mist of the opposing quality. For the orange, yellow, yellow-green, and blue-green papers this latter quality was purple. The red paper showed bright yellow patches, the blue simply darkenings, the purple bright green blotches, and the violet a general whitening of the field. In the case of the green, the purple color persisted during two minutes' continuous fixation in sunlight. In all of these observations only one eye was externally stimulated at one time.

It would be foreign to the purpose of the present paper to attempt a theory of the phenomena just described. Their sufficient significance in the present connection lies in the proof which they offer of the fact that, under certain con-

ditions, the disappearance of the primary quality of a stimulus may be due to processes initiated in the retina of the eye opposite to that exposed to the action of the stimulus in question.

IX. Conclusion

The purpose of the present paper has been to show that—contrary to the requirements of the Hering theory in its ordinary form—a visual sensation is not a process—like those of the classical theory of available energy—which goes on only at the cost of its final self-destruction. That specific adaptation reduces the sensitivity of the visual cells to a very marked degree cannot be gainsaid; but that this reduction is such as, with continued stimulation, to bring all stimuli to equivalency it is the object of the foregoing admittedly incomplete studies to disprove. Stimuli of low intensity may readily be carried below the threshold by adaptation, but the tests and measurements described in the present paper demonstrate that by far the greater number of visual stimuli which act upon our eyes in everyday life are of the constantly supraliminal equilibrium type both with respect to brilliance and to saturation.

In another place the author[1] has suggested a modification of the Hering theory which will permit one to account for the elevation of the threshold through adaptation, and which at the same time sets definite limits to this process, which are determined by the nature of the stimulus. This view provides a basis for the theoretical study of sub- and supraliminal equilibrium sensations in general. The essential conceptions and assumptions involved may be outlined briefly as follows.

Let us suppose that the intensity of a given component, V, of the visual sensation is such a function of a katabolic rate of change of the concentration, s, of the visual substance, S, in the retinal end cells as we have previously defined. Chemical principles lead us to suppose that this katabolic rate, q, will not be zero even in the absence of light, and that

[1] Troland, L. T., 'Adaptation and the Chemical Theory of Sensory Response,' *Amer. J. of Psychol.*, 1914, 25, 500–528.

its magnitude will be proportional at all times to the concentration of the substance at the time. If we assume the reaction to be irreversible, the spontaneous decomposition in question may be represented by the equation:

$$k = c_k s, \tag{10}$$

where c_k is a constant. Similarly, the component of the rate due to the action of light may be represented by the equation:

$$d = c_d i s \tag{11}$$

in which i is the light intensity. In order to maintain the process, repair is necessary, and if this repair consists of a flow of substance into the cell which is governed by osmotic principles, it should follow an equation similar to:

$$a = r - c_r s, \tag{12}$$

where a is the rate of inflow, c_r a constant, and r another constant, whose magnitude depends upon the concentration of the nutritive substance in the lymph outside the cell.

It will be clear from a consideration of the above equations that, on the basis which they provide, the total rate of change of s, which latter variable is equivalent to the sensitivity of the cell, must be

$$ds/dt = a - k - d \tag{13}$$

or

$$ds/dt = r - (c_r + c_k + c_d i)s. \tag{13a}$$

But at equilibrium $ds/dt = 0$, for which value equation (13a) can be reduced to:

$$s = r/(c_r + c_k + c_d i), \tag{14}$$

which states that the more intensive the stimulus with which the visual cell comes into equilibrium, the lower will be its equilibrium sensitivity. Now, we have assumed the intensity of the sensation to be proportional, in some sense, to the katabolic component of the change in s. This component obviously has the value:

$$q = (c_k + c_d i)s, \tag{15}$$

or, for equilibrium, from (14):

$$q = r(c_k + c_d i)/(c_r + c_k + c_d i), \tag{16}$$

in accordance with which the rate of the katabolic process at equilibrium must be higher the higher the intensity, i, of the stimulus.

If, in equation (16), we place $i = \infty$, we find $q = r$, which shows that, with increasing stimulus intensity, q approaches r as a limit, thus revealing equation (16) as a statement, for equilibrium conditions, of the general relationship formulated in Fechner's law. An analysis of the value of di/dq yielded by the equation in question shows that it accounts for the so-called upper and lower deviations from Fechner's law, as well as for the general relation. If we place $i = 0$, we find from (16) that

$$q = rc_k/(c_r + c_k), \tag{17}$$

which corresponds with the sensation from a retina at equilibrium with darkness, or with rest idio-retinal light. If we suppose the discrimination threshold for the visual component, v, stated in terms of q to be Δq, it is obvious that a given stimulus will be of the supraliminal equilibrium type if its intensity, i_p, is such that:

$$\frac{r(c_k + c_d i_p)}{(c_r + c_k + c_d i)} - \frac{rc_k}{(c_r c_k)} > \Delta q \tag{18}$$

and will be of the subliminal equilibrium type if the inequality is reversed in direction.

In considering the question as to the causes underlying the fluctuations of visual sensation, one must carefully avoid preconceptions, since this field of investigation is extremely full of complexities. The view that such fluctuations are due to deviations of the attention seems obviously to have been supported by prejudice rather than by either theoretical or empirical analysis of the facts. However the writer deems it probable as a result of certain observations of his own that, especially with threshold stimuli in the dark, the whole visual field—so far as regards detail—may sometimes lapse from consciousness, by a process seemingly describable as failure of attention. That attention to visual objects goes regularly in the form of waves, which set a definite limit to the length

of time during which such an object can be continuously perceived, seems to the writer, on the basis of the work described above, very doubtful.

Ferree[1] has attributed certain visual fluctuations to the effects of 'the streaming phenomenon,' or the surgings of the idio-retinal light. As already noted, the present writer's observations tend to bear out this view with regard to liminal stimuli seen with the artificial pupil. When the idio-retinal field is quiet there are far less marked fluctuations in the visibility of the liminal stimulus, and the intensity which is necessary in order to maintain it constantly in view is lower than when strong surgings of the idio-retinal light are present. The blotting out of spot stimuli by the idio-retinal surgings appears to be a matter rather of swamping than of inhibition. If the intensity of the stimulus is increased so that the sensation which it causes is always perceptibly greater than the brightest of the idio-retinal waves, it shows no disappearances. Accordingly it seems probable that disappearances due to the streaming phenomenon should be attributed to momentary increases in the value of the second complex term in equation (18), which causes the difference between the two terms to become less than Δq.

Momentary disappearances of a visual stimulus may sometimes be due to rapid eye-movements which, as Holt[2] has shown, are accompanied by central anaesthesia. Even if there were no such anaesthesia, the sensation might lapse, in the case of minimal stimuli at least, owing to the speed of the movement and the consequent lowering of the time of action of the stimulus upon a given retinal point. In such cases the stimulus would reappear again almost immediately, as fixation was reëstablished. Some of the observed disappearances of very dim lights are so nearly instantaneous as strongly to suggest an explanation of this sort.

The reappearance of stimuli of subliminal sensory equilibrium as a result of recovery during eye-movement is also,

[1] Ferree, C. E., 'The Streaming Phenomenon,' *Amer. J. of Psychol.*, 1908, 19, 484–503.

[2] Holt, E. B., 'Eye-Movement and Central Anæsthesia,' Psychol. Rev. Monogr. Suppl. No. 17. *Harvard Psychol. Stud.*, 1903, 1, 3–46.

of course, a distinct possibility. This would apply only for values of the stimulus intensity, i, for which the inequality of (18) has a reversed direction.

Phenomena of binocular interference, or retinal rivalry are probably of importance for the explanation of certain special cases of disappearance, as shown by the observations described in the just preceding Section.

When considering the problem of the quality of the equilibrium sensation with respect to Hering's views it is especially necessary to treat independently of brilliance and of hue. Given components of the original sensation may disappear at equilibrium without necessitating that the whole should fall to the level of mid-gray. Adaptation weakens all of the chromatic components more than it does the achromatic. Since it seems likely that each of the six fundamental components of the visual sensation has a retino-cerebral apparatus which is more or less independent of that of the others, each of them may be considered as having separate equilibrium conditions, which must be quantitatively determined before any definite prediction can be made concerning their behavior. The experiments which we have reported above indicate that a spectral stimulus, for example, may be of the subliminal equilibrium type with respect to one sensory component (say R), while it is not so for another (as B). All experiments which demonstrate a photochromatic interval at the threshold for equilibrium must be interpreted from the same point of view, the equilibrium conditions for the hues involved being considered independently of those for the 'gray' component.

It is necessary, however, with regard to the disappearance of part components of the visual sensation, to consider not only the independent properties of these components but also the laws of their mutual interaction, in particular their relations of antagonism or complementation, and the manner in which they are capable of overwhelming one another. The disappearance of R and G at high intensity equilibrium may be assigned not so much to the fact that they have low absolute equilibrium sensation intensities as that these intensities are *relatively* low compared with those of Y, B, and W.

It is probable, also, that at high intensities the relation of antagonism enters in, since if each of the components approaches an asymptotic limit with increasing intensity, the same values will be attained by antagonistic excitations at high intensities of any stimulus, regardless of the wave-lengths which it includes, and it is naturally to be assumed that at such limits the antagonists, being probably at about equal strength, will either inhibit each other or combine to form white. In either case the two antagonistic qualities will be eliminated as possibilities in sensation. For very low intensities it is probable that, through dark adaptation, a marked increase in the sensitivity of the achromatic mechanism, relative to that of the chromatic, may cause a disappearance of color components through 'swamping.' This is probably true in the case of the achromatic interval in the blue, since at both very low and very high intensities the blue of the spectrum yields a sensation having a strong *W* component.

All of the above considerations apply to observations with the artificial pupil as well as to those in which the natural pupil is free to modify the effective intensity of the stimulus. In the latter case, however, the writer is convinced that with stimuli of ordinary intensity, practically all of the observed fluctuative disappearances are due to the activity of the iris. Several types of fluctuation caused by the pupil may be suggested. The first applies to a subliminal equilibrium stimulus. We will suppose that the sensation has reached equilibrium with a fairly wide pupil and that it has fallen below the threshold. If the pupil now contracts, recovery will set in, that is, the level of sensitivity will be raised in accordance with equation (14), owing to the weakness of the effective stimulus with which the organ is in equilibrium. When the pupil expands once more the stimulus momentarily reappears. It is clear that whether a given external stimulus is one of subliminal or of supraliminal equilibrium may be determined by the size of the pupil itself, since this affects the energy reaching the retina just as does an actual variation in the external illumination. Hence a second case may be suggested in which a subliminal equilibrium is reached with a

small pupil, this being followed by pupillary expansion such that the increased effective intensity now yields a supraliminal equilibrium sensation. In this case the stimulus should not disappear again until another contraction of the pupil ensues. A third type of fluctuation caused by the pupil would be that of a simple 'dimming effect,' which requires that the visual cells be fatigued by a light of relatively high intensity—wide pupil—which is then dimmed—narrowing of the pupil. A dimming effect of this sort may be produced regardless of whether the stimulus is one of sub- or of supraliminal equilibrium intensity, although with the former alternative the disappearance would be only momentary, even if the pupil remained contracted. Two cases are really involved here, however, one of the simple dimming effect, and one in which the pupillary contraction brings the effective stimulus below the equilibrium threshold. It is probable that the simple pupillary dimming effect is the principal cause of fluctuations in free vision, a view strongly supported by the fact of their absence with stimuli of high intensity.

The argument of the present paper, directed as it is against Hering's conclusion that all equilibrium sensations are neutral mid-gray, nevertheless admits that complete disappearances of visual stimuli—such as Hering adduces in support of his theory—actually occur. However, it is intended to prove that such disappearances take place only under definite special conditions and should not be interpreted as demonstrating the evanescent quality of all fixed visual sensations. What some of the special conditions are under which disappearances do occur, we have tried to make clear, as well as to show how these disappearances are consistent with a theory of visual response which does not, like that of Hering, imply a common dead level for all equilibrium sensations.

ON ATTENTION AND SIMPLE REACTION

From the Psychological Laboratory of McLean Hospital[1]

F. L. WELLS, Ph.D.
in charge

C. M. KELLEY, M.D.
Associate

GARDNER MURPHY, A.M.
Assistant

1. The variations of the simple reaction time to a constant stimulus are generally conceived as expressing fluctuations of "attention." Attention is thus used to denote a condition of the nervous system which, when it is 'high,' allows the simple reaction process to run off quickly, and when it is low, more slowly. The degree of 'attention' at any given moment of stimulus is given in the speed with which the reaction takes place.

2. Many attempts have been made to find how certain conditions of stimulation affect attention as measured in this way (1). These center about the control of an interval elapsing between a warning signal and the stimulus for reaction; here termed the prestimulus interval. After the warning signal is given, the curve of attention follows a course whose variation can be plotted for different individuals and for different expectations. If the subject knows a stimulus is coming in four seconds, his attention will be higher at that moment than if he does not know whether the stimulus is coming in one or ten seconds.

3. There seems however to be a narrow zone within which attention is relatively higher than for other prestimulus intervals. This zone of most favored intervals may be stated as from two to four seconds, with a leaning towards two. Shorter and longer intervals than these are generally less favorable, *i.e.*, give longer reaction times.

[1] As of August 1, 1920.

4. Outstanding pieces of work on this problem have been done by Breitwieser (2) and by Woodrow (3). Breitwieser gave some study to the comparison of sound and light stimuli in series where the subject did not have foreknowledge of the prestimulus interval. His general results on this point are given in the following figures derived from those quoted by him:

	Prestimulus Interval, Seconds									
	1	2	3	4	5	6	7	8	9	10
Percent which the average for the given prestimulus interval is of the average for all prestimulus intervals:										
Sound Reactions...	100.3	97.8	98.3	99.8	101.2	101.6	98.1	100.3	101.9	100.9
Do. for Light Reactions....	112	97	95	93	98	99	102	101	102	101
Percent which the Light Time is of the Sound Time (Sound-Light Ratio)	161	143	139	134	140	141	150	144	144	145

5. Breitwieser's work has a special significance for the present study through his having taken up reaction times to visual as well as auditory stimulus. Unfortunately the groups of subjects are not the same, six for the visual, eighteen for the auditory. In average, the sound-light ratios differ somewhat according to prestimulus interval. The one-second interval is the most favorable for sound (sound-light ratio 161), the four-second interval the most favorable for light (sound-light ratio 134). This result is specially interesting, as it indicates a different curve of attention for sound and light, or that attention to a sound stimulus is something different from attention to a light stimulus. In the writers' normal data, such a finding does not appear in group average, but is well established for one subject, K. His average sound-light ratio for the one-second prestimulus interval is 139, for the three-second prestimulus interval, 129. This is in accord with Breitwieser's averages for these intervals, 161 and 139 respectively. The light is favored by the longer interval. Apparently sound attention here "rises" more rapidly than light attention.

6. Mention has been made of the factor of expectation in the present problem. In Breitwieser's chief work, the prestimulus intervals are one to ten seconds, without foreknowledge. In Woodrow's chief work, the prestimulus intervals range from one to twenty-four seconds with foreknowledge; that is, the subject knows that the succeeding prestimulus interval will be the same as the last, till a change is announced. Woodrow's procedure gives shorter and more regular times than Breitwieser's. In the present study, the conditions of expectations are more favorable than Breitwieser's, less favorable than Woodrow's. The subject does not know what the prestimulus interval is going to be, but it is actually always close to three seconds or one second. This is more favorable than a lack of foreknowledge with a possible range up to ten seconds. It is probably also more favorable than foreknowledge of long prestimulus intervals such as 8 seconds or more. It is not so favorable as foreknowledge of prestimulus intervals of the order of those used in the present experiments. Owing to this difference in expectations, the present results are rather complementary than strictly comparable to the results of either Woodrow or Breitwieser.

7. Working with unpredicted prestimulus intervals, over a range of 1 second to 10 seconds, Breitwieser found only small differences between the various intervals. The most favored, 2 seconds, is 131 sigma, the least favored, 9 seconds, is 136 sigma. The most favored prestimulus interval for light is 4 seconds, 177 sigma, the least favored 1 second, 215 sigma, which is outstandingly long. His mean variations run 10–14 percent of their averages. A mean variation for a prestimulus interval, when large, indicates that the attention curve is especially subject to *fluctuation* at that point; when small, that at this point the attention curve is usually just about a certain height. Very distinct differences of this kind are hardly to be expected in the given conditions; it is however fairly clear that under these conditions it is the one-second interval that fluctuates the most, for both sound and light stimuli.

8. In Woodrow's work, with predicted prestimulus intervals, there is much more difference between the reaction

times for the different intervals, and they are in turn more constant. Two seconds is again most favored; one second is next. Mean variations run some 10 percent of their averages. As with Breitwieser, the most *fluctuation* is shown in the 1-second interval. The amount of fluctuation for the successive prestimulus intervals grows at first smaller and then larger again, the smallest amount of fluctuation being found at the 12-second interval. It is perhaps a freak of chance that at this point also the amount of variation shown by the three subjects differs by a mean of but two tenths of one percent. Absolutely, the fluctuation is greatest for the longest prestimulus intervals, which have much the longest reaction times.

9. The following figures represent the amount of fluctuation in the attention curve at the different prestimulus intervals. They are the average ratios of the reaction time averages to their mean variations (percent which the m.v. is of the average), and the mean variation of this average ratio for the three subjects.

FLUCTUATIONS IN DEGREE OF READINESS AT DIFFERENT PRESTIMULUS INTERVALS (DERIVED FROM WOODROW)

	Prestimulus Interval (Seconds)							
	1	2	4	8	12	16	20	24
Fluctuation av.	11.8	10.5	8.9	9.6	8.6	10.9	9.7	10.7
M.v.	1.6	3.3	1.0	.4	.2	.9	.8	.7

10. With unpredicted prestimulus intervals ranging from 3 to 7 seconds, and from 4 to 20 seconds, Woodrow found in both cases the shortest interval to be the least favorable. This further indicates the important rôle played by the conditions of expectation in the attention adjustment. Woodrow believes that unpredicted prestimulus interval has a generally unfavorable effect on the shortest interval.

11. Turning now to the present experiments, their conditions of expectation have been described. The subject does not know what the prestimulus interval will be, but it always

approximates 1 second or 3 seconds. How the reaction times under these two intervals compare, is expressed by a ratio, the percent which the three second interval is of the one-second interval. When this figure is above 100, the one-second interval is the more favored, and vice versa.

12. The general average ratios for a group of 13 subjects (the "A-group," 216 observations each, 216 × 13 = 2,808) compare as follows with those of two subjects (11 experiments each, 216 observations, 11 × 216 = 2,376, total observations 7,560):

PERCENT WHICH REACTION TIMES WITH 3-SECOND PRESTIMULUS INTERVAL ARE OF THOSE WITH 1-SECOND PRESTIMULUS INTERVAL

	A-group	K	W
Av.	96	100	98
M.V.	4.5	.7	2.6

13. There is shown general tendency to favor the three-second interval, though in subject K the two are similar; the range of the A-group is from 85 to 104. This is what might be expected from previous work, since one second has appeared to lie rather ahead of the most favored interval, and three seconds, while perhaps slightly beyond it, is still in the most favored 'zone.' The conditions of expectation unfavorable for this interval, described by Woodrow, so far as they obtain here, now affect rather the one second interval. One second represents an interval during which attention has not had time to reach its maximum; at three seconds it is nearer the maximum, but has probably slightly passed it. Neither K nor W show practise effect in this function of the experiment.

14. Mention has been made of evidence that the prestimulus interval may act differently upon sound and light stimuli. Subject K alone shows this clearly, and the most direct statement of it is in the following figures:

PERCENT WHICH THE THREE-SECOND INTERVAL IS OF THE ONE SECOND INTERVAL IN SOUND AND LIGHT REACTIONS (SUBJECT K ONLY)

	Sd. 1st Half	Sd. 2d Half	Lt. 1st Half	Lt. 2d Half
Av.....	104	105	95	97
M.V.....	3.6	3.6	2.9	3.5

15. The apparent equality of the two intervals in K (pars. 12, 13) is seen to be the resultant of favoring the one-second interval for sound and the three-second interval for light. The other subjects do not show this, and no indication is furnished of its being a general phenomenon, or a product of the present experimental conditions. The generally better coördination of movement to sound than to light would make the result easier to interpret as a generality than as the idiosyncrasy it appears to be.

16. Differences between the two prestimulus intervals represent the height of the attention curves at those times. If the one second is favored, it indicates a rapid summoning of readiness (though not necessarily to a special height) which soon falls off. Favoring of the three-second interval indicates a slower and (perhaps) better sustained summoning of attention. The *quickness* with which attention is summoned is thus indicated by the most favored prestimulus interval; the *height* to which it is summoned by the comparative speed of the reaction at this period. Inquiry is made as to possible relation between the quickness with which attention is summoned and the height which is reached.

17. The question is if faster reactions are related to a favoring of the one-second or the three-second prestimulus intervals. The more favored interval is indicated by a ratio (par. 11); the more this ratio is below 100, the more the three-second interval is favored. This ratio, for all observations, is correlated with the central tendency for speed in all observations. For the A-group the rank difference is $\rho = -.27$ (r, 28). If sound reactions alone are considered, this figure becomes smaller, $\rho = -.22$ (r, 23) (Scott Co. Tables). Accordingly what tendency there is, is for the *quicker* summoning

of attention to go with higher summoning, as indicated in generally shortening the reaction time.

18. This does not apply to performances of the same subjects (K and W) on different days. No correlation between these factors can be asserted for the records of subject W, and with K an opposite situation appears. For all his reactions, the ρ of the two factors is .31 (r, 32), and for sound reactions only, .50 (r, 52). This individual tends to react more rapidly when he favors the three-second interval, but it is to be noted that his variations in this respect are quite slight (par. 12).

19. In par. 7 was raised the question of the *fluctuation* in the height of the attention curve at any given point after the warning signal. This is expressed in the variability of the reaction times within their unit-series. In the present experiments the criterion of such variability is the percent which the *upper* quartile is of the median (for each unit-series of 27 reactions), termed the "quartile ratio."

As these figures throw light on the dispersion of the measures in general, as well as on the particular question of fluctuation, they are quoted in some detail as follows:

PERCENT WHICH UPPER QUARTILES ARE OF MEDIANS IN THE VARIOUS REACTION PROCEDURES

	A-group		K		W	
	Av.	M.V.	Av.	M.V.	Av.	M.V.
Sound, 1", first half	114	6.0	114	4.5	111	3.6
Sound, 3", first half	114	7.9	112	3.5	111	4.2
Light, 1", first half	113	5.8	108	2.6	108	4.3
Light, 3", first half	110	2.7	108	1.9	106	1.8
Sound, 1", second half	113	3.4	112	4.1	113	3.2
Sound, 3", second half	114	4.3	111	2.6	115	3.8
Light, 1", second half	116	7.5	108	3.5	109	2.7
Light, 3", second half	111	3.4	108	1.8	107	2.5

20. There seems, for the light stimulus, to be very slightly more fluctuation at one second than at three seconds. The results are, however, characterized rather by uniformity. Under the present conditions, the attention curve is hardly

if at all subject to more fluctuation at one point than at another. That it is ofter *higher* at certain points than at others, has been, of course, abundantly attested.

21. This is the concluding one of three brief reports of recent simple reaction observations with normal individuals at the McLean laboratory. As already remarked, they were undertaken for comparative studies with pathological cases, with whom more extensive observations have been made. The first report of these latter is in press (4).

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